DOCTOR OF PHILOSOPHY

Monitoring desertification in south west Tripoli using multi-temporal remotely sensing data and GIS

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Award date:
2006

Monitoring desertification in south west Tripoli using multi-temporal remotely sensing data and GIS

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University of Dundee

UNIVERSITY OF DUNDEE

MONITORING DESERTIFICATION IN SOUTH WEST TRIPOLI USING MULTI-TEMPORAL REMOTELY SENSING DATA AND GIS

By
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A thesis submitted to The Department of Electronic Engineering and Physics of The Faculty of Engineering, in fulfilment of the requirement for the degree of Doctor Philosophy (PhD)

University of Dundee, UK
September, 2006

ABSTRACT

Remotely sensed data has potential value for vegetation change detection and mapping in arid/semi-arid environments, which can be used and analysed to extract information relevant to the understanding of environmental hazards. This provides useful information for the study of desert environments and desertification monitoring, assessment and mapping. In Libya, the vast agricultural development which occurred during the last decades was accompanied by desertification of different areas. Desertification varied in type and degree according to the geographical site, irregularity of rainfall and the prevalence of strong wind which significantly affects the stability of the fragile ecosystem.

The potential of this study was to offer answers to the understanding of desertification indicators and has identified criteria for desertification assessment and the creation of land degradation maps using remote sensing data and a geographic information system (GIS). The indicators which mainly impact the study area are wind erosion, vegetation degradation, salinization, and deterioration of water resources *etc.* Landsat TM imagery has been used as a source of data to monitor land cover and its change over large areas.

In this study, multi-temporal Landsat TM imagery has been used in order to map land cover and their changes during five-year intervals from 1988 to 2000. This was achieved by using a soil adjusted vegetation index formula to detect vegetation The algorithm classification technique has been used to map vegetation cover, Eolian Mapping (EM), vegetation of various densities, by used the Soil Adjusted Vegetation

Index (SAVI) images: TM 1988, TM 1992, TM 1996 and TM 2000. The results of this technique show areas that have vulnerability to wind erosion susceptibility, and change detection algorithm has been used to calculate the vegetation changes in the period from 1988 to 2000. This is therefore one land degradation factor that can be created from remotely sensed data. The analysis clearly demonstrates a net decrease in vegetation cover. This situation exemplifies the deterioration of the natural vegetation cover. The information derived from remotely sensed data has been integrated in a GIS to identify relevant factors for developing a spatial model for desertification assessment and mapping. A Geographic Information System was used to combine and interpret a range of parameters (land cover, soil type, topography, climate, etc.).

This study presents an efficient methodology to delineate the land degradation factors in study area, in a GIS environment. In this study have used one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP) which provides a systematic approach for assessing and integrating the impact of various factors, involving several levels. The methodology has been present for computing a composite index of land degradation factors derived from topographical, land cover, soil type and climate data. All data are finally integrated in a GIS environment to prepare a final desertification map. This land degradation factors computed from AHP method not only considers susceptibility of each area to emphasize the vulnerability of land to erosion but also takes into account the factors that are related to desertification.

A result of the GIS analysis is the production of maps showing wind erosion, vegetation degradation and salinisation. The final stage of this study was the construction of a desertification map showing areas affected by different types of land degradation.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor, Dr. Robin Vaughan for his encouragement, advice, support, and patient in the supervision of my work. I also wish to thank Dr. Mark Cutler for his valuable suggestions and very useful advice.

Especial thanks to the Biruni Remote Sensing Centre for facilitating my study by providing financial support during this study,

I would like to thank all agencies and institutions, in Libya and that provided me with vital information which assisted in the formulation of this thesis.

Finally, Especial thanks to my family who have all given me support during this time. They have all helped to make my time away from home comfortable and memorable.

DECLARATION

I hereby declare that the following thesis has been compiled by me and that it has not previously been accepted for a higher degree at this University or any other institution of learning.

....

Omar Oune

CERTIFICATE

This is to certify that Omar Oune has carried this research under my supervision and that has fulfilled the conditions of Ordinance 39 of the University of Dundee, so that he is qualified to submit for the Degree of Doctor of Philosophy.

Robin Vaughan

....

Dr. Robin Vaughan

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CHAPTER ONE

INTRODUCTION

1.1 Background

As in most countries, particularly those situated in the arid and semi-arid belt, agriculture and animal production in the Libyan Arab Jamahiriya are the economic activities most closely associated with issues of desertification and most affected by the different aspects involved; on the one hand, they are entirely reliant on the fundamental elements of renewed natural resources and land, while, on the other hand, the direct effect which they have on the status and productive capacity of these elements can be either positive or negative depending on the combination of a number of economic factors, social influences and environmental conditions and the interaction between them.

Desertification refers to land degradation in arid, semi-arid, and dry sub-humid areas resulting from climatic variations and human activities. In the definition proposed by the UN Convention on Desertification (UNCOD), desertification is considered the result of a series of natural and anthropogenic processes, leading to gradual environmental degradation or loss of the land's biological or economic productivity (UNEP, 1994).

Nowadays, reduction in natural resources and agricultural soils is increasing more than ever as is the removal of vegetation which provides protection against degradation processes. Decrease of vegetation cover is a sensitive indicator of desertification. In Libya, about 95% of the country is desert. The cultivated area is estimated at about 2.2 million ha, which is 1.2% of the total area of the country. Permanent pastures account for 13.3 million ha, annual crops for 1.8 million ha and permanent crops for only 0.3 million ha, (FAO, 2000).

The northwest of Tripoli in Libya suffers from desertification problems which include increased use of marginal lands for crops and grazing, due to population growth and pressure accelerating soil degradation and erosion due to inappropriate agricultural practices, escalating deforestation due to growing needs for fuelwood, building materials, cropland and urban expansion. Expanding desertification is also due to overstocking, overgrazing and inadequate range management. In addition to social problems, ecological, geographical and climatic conditions have particularly favoured intense degradation of natural resources, persistent erosion and desertification processes. This has produced significant risks of water quality deterioration and depletion of fresh water biodiversity, both plant and animal.

Remote sensing systems provide significant contributions to desertification assessment and monitoring, particularly by providing methodological pathways for scaling up the results of field investigations and by supplying the spatial information needed for regional scale analysis of the relationships between, land degradation and desertification processes.

The advent of satellite imagery, coupled with the collection of spatial data, has helped demonstrate the impact of desertification and provide the data needed for improving the situation. However, GIS not only allows researchers to view and manage land cover, natural vegetation, soil types, climate, topography, and socioeconomic data but also to analyze it all within one framework. GIS is proving a most effective tool for studying this complex phenomenon (*www.esri.com/environment*). This present study illustrates the dynamics of land cover changes and the major indicators to the desertification assessment and mapping over the study area during the twelve year period and five year intervals, using mainly remotely sensed data and a geographic information system (GIS).

1.2 Research Objective

The primary goal of this research is to understand the dynamics of desertification in the study area and to focus on using remote sensing data and geographic information sensing techniques (GIS) in order to monitor the land cover changes over time, and mapping the vulnerable areas of desertification. The general aim can be split into the following specific objectives:

- To detect and evaluate the dynamics of land cover changes that is taking place over a period of time, using multi-temporal Landsat TM images. At what rate does the land cover change progress and when did it start?
- To integrate digital satellite with ancillary data in a geographic information system and up-to-date information in spatial and non spatial forms
- To identify factors which are relevant to the evaluation of the desertification assessment and mapping
- To integrate satellite data in a geographic information system (GIS) with desertification factors to produce a desertification map of the study area.

1.3 Data Used

In order to monitor the desertification processes in the study area, the following data were used

- Digital topographic maps at scale 1: 50000, produced in 1980
- Land use map at scale 1: 50000, produced in 1980
- Soil map at scale 1: 50000, produced in 1980
- Landsat TM [(1)], satellite imagery (table 1.1 and figure 1.1)

Table 1.1: satellite images used in the present study

Sensor	Path/Row	Date	Platform
TM	189/37	15.08.1988	Landsat 5
TM	189/37	20.08.1992	Landsat 5
TM	189/37	25.08.1996	Landsat 5
TM	189/37	26.08.2000	Landsat 5

- Climate data. Unfortunately some of the stations were out of action for long time. Climate data were available at 5 stations in study area over the 20 years-period 1980- 2000. (Figure, 1.2)

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(1) Thematic Mapper (TM): The TM was flown on Landsat-4 and Landsat-5. The TM is a cross-track scanner providing seven multispectral channels (3 visible, 1 near-infrared, 2 mid-infrared, 1 thermal-infrared) at 30-meter resolution (120-meter resolution for the thermal-infrared band).

TM bands 4. 5 and 3 RGB (1988)

TM bands 4. 5 and 3 RGB (1992)

TM bands 4. 5 and 3 RGB (1996)

TM bands 4. 5 and 3 RGB (2000)

Figure 1.1 multi temporal Landsat TM

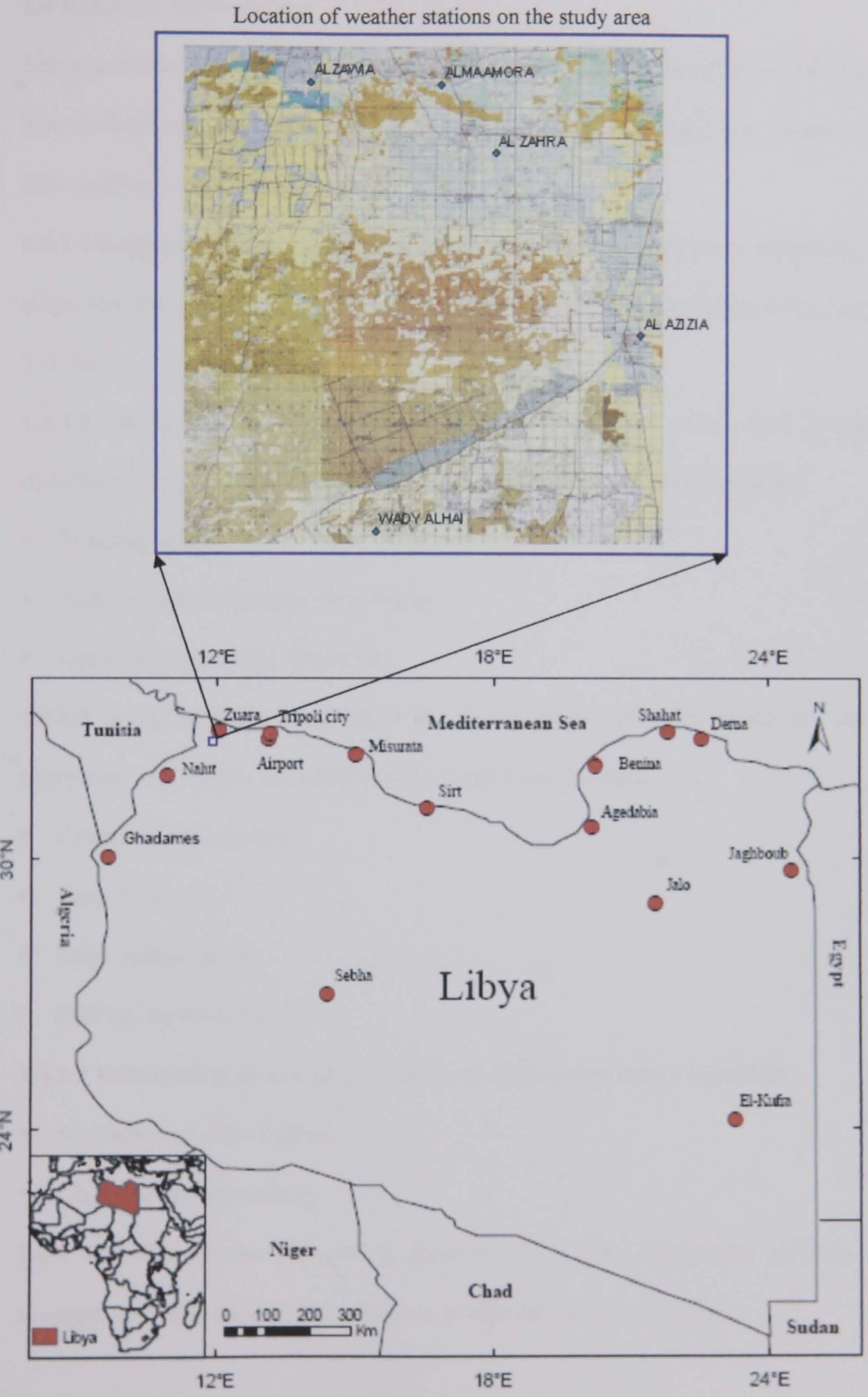


Figure 1.2. Locations of weather stations map

Source; Metrological Department

1.4 Research Methodology

The procedures of the study are shown in the chart which is illustrated in figure (1.4). The methodology is categorised into phases of remotely sensing data analysis, GIS data analysis and modelling

1.4.1 Image processing, methods are grouped into three functional categories; this stage describes and illustrates the major categories of image processing using Landsat TM data

1.4.1.1 Image restoration compensates for data errors, noise, and geometric distortions introduced during the scanning recording and playback operation

- Filtering noise
- Correcting for atmospheric scattering
- Correcting geometric distortions

1.4.1.2 Image enhancement alters the visual impact that the image has on the interpreter in a fashion that improves the information content.

- Contrast enhancement
- Density slicing
- Edge enhancement
- Making digital mosaics

1.4.1.3 Information extraction, classifies on the basis of digital signatures

- Multispectral classification
- Change-detection images

1.4.2 GIS Operations this part is grouped into spatial data input, attribute data management, data display, data analysis, and modelling process (figure 1.3).

Spatial data input	1. Data entry: use existing data, create new data 2. Data editing 3. Geometric transformation 4. Projection and reprojection
Attribute data Management	1. Data entry and verification 2. Database management
Data display	Use of maps, tables
Data exploration	1. Attribute data query 2. Spatial data query 3. Geographic visualization
Data analysis	1. Vector data analysis: overlay, map manipulation 2. Raster data analysis: terrain mapping and analysis 3. Spatial interpolation
GIS modelling	Suitability Model (SM)

Figure 1.3. Classification of GIS processing

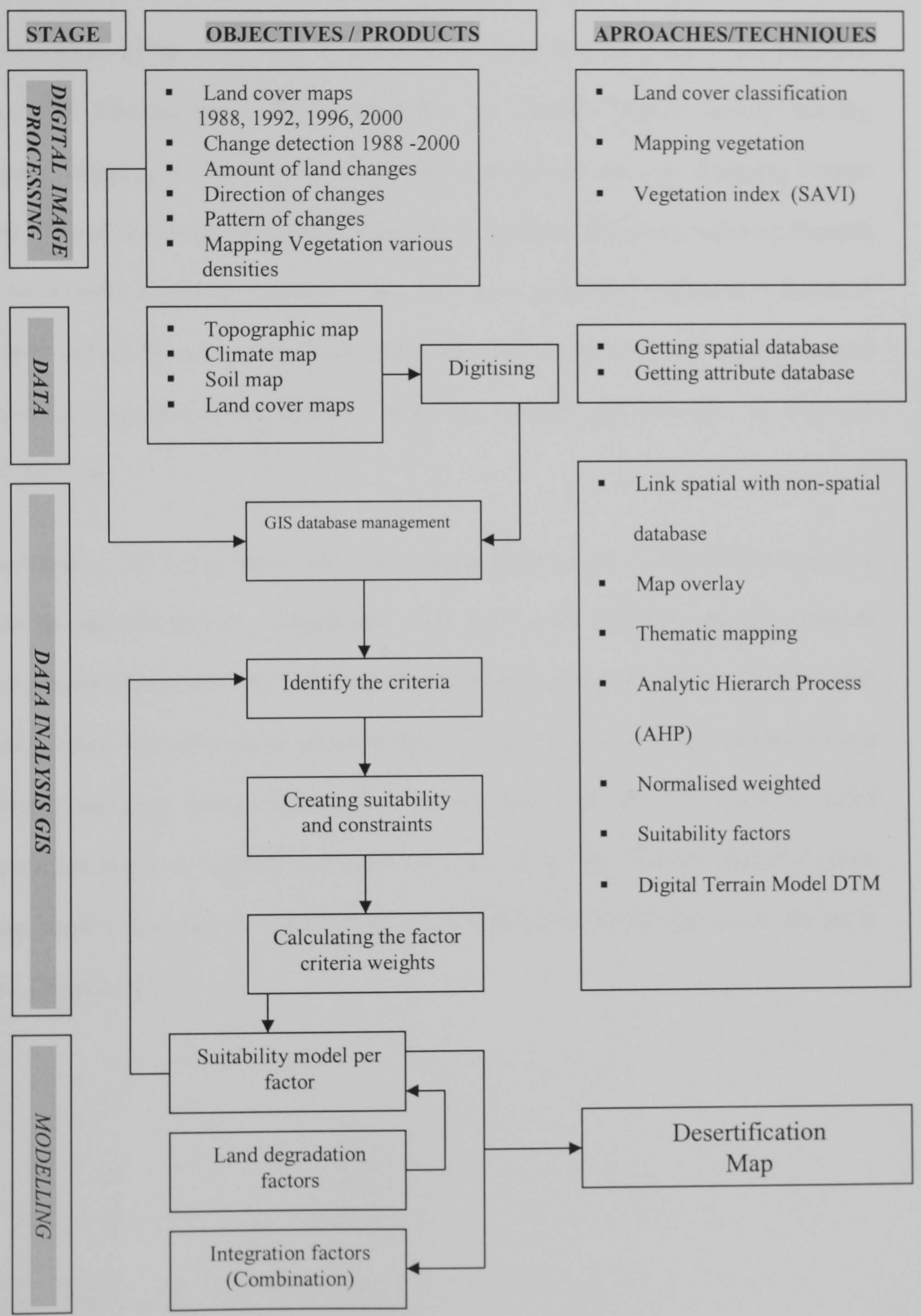


Figure 1.4. Methodology Flow Chart

1.5 Fieldwork study in Libya

The present study is based on satellite images but also on field investigations in southwestern Libya. Fieldwork was carried out from June-July 2004. All reference data were collected from Libyan authorities: the library of Biruni Remote Sensing Centre; Mapping of Natural Resources for Agricultural use and Planning Project (FAO, Libya 00/004); Libyan Meteorological Department (Climatic Section); General Environmental Authority; General Water Resources Authority; Agricultural Research Centre; and the libraries of El-Fateh University, Tripoli, and the field trip was carried out in the study area in the region of El-Azizia, El-Zahra, EL Hahshan, EL Mamora and Birkuka .

The Landsat TM image from 1988 and topographic maps at 1:50 000 were used as a basis for specific feature recognition. Fifty sites were visited to provide detailed background information on vegetation communities and associated landforms and soils. Sites were selected to represent the main land cover units and located using a Global Positioning System (GPS). This process was undertaken to facilitate direct association between vegetative cover on the ground and the different imagery types, some photos were taken to clarify some of desertification manifestations on the study area. (Figure 1.5)

Figure 1.5.A and B. Some of desertification manifestations on the study

1.6 computer programs used

Illustrations and data analyses contained in this study were achieved using different programs: ER Mapper 6.3, Arc GIS 8.1, MapInfo 7.0 with extension of Vertical Mapper 2.6 (*contour modeling & display software*) and Excel 2000 in addition to the general cartography skills. The full text of the thesis is typed using word processing (Word 2000) system.

1.7 Outline of the Study

Following this first and introductory chapter, the thesis is divided into nine further chapters.

This study is laid out as follows.

- Chapter one has described the study in general. It has covered the background and objectives followed by conceptual methods.

- Chapter two describes the location and physical setting of the study area

- In chapter three, the desertification characteristics in Libya are described. Its manifestations its causes and its effects are discussed. It attempts to give the conceptual foundations of desertification in general. Desertification on a global level in the Arabic region is briefly reviewed in order to present common causes.

- Chapter four investigates the potential of remote sensing and its applications to monitoring desertification processes in desert environments, in particular Landsat TM data, which has been used in this study

- Chapter five. This chapter investigates and explains the necessary background information and the integration of indicators using geographic information system (GIS) techniques and background of the model which has been used.

- Chapter six. In this chapter three main results have been derived through a variety of image processing techniques on Landsat TM imagery. Land cover change maps have been updated, land cover change detection is shown, and the existing database is updated.

- Chapter seven. This chapter is focused on vegetation mapping and monitoring, Eolian Mapping (EM) and vegetation changes in period of time 1988 to 2000 used Landsat TM as source data via the Soil Adjusted Vegetation (SAVI) Index.

- Chapter eight. Presents the way of planning policies and models and the results of remote sensing data analysis which have been integrated using geographic information system (GIS) to develop a model for desertification assessment and mapping.

- Chapter nine presents the conclusion of this study, limitations and recommendations of the direction for further studies in the desertification assessment and mapping.

CHAPTER TWO

PHYSICAL SETTING OF THE STUDY AREA

2.1 Location and population of Libya

The Libyan Arab Jamahiriya is situated in North Africa between 20° and 37° north and between 10° and 25° east. It is about 1.75 million square kilometres in extent. More than 95 percent of the country is desert. Cultivatable areas cover an estimated 3.8 million hectares, slightly over two percent of the total area (Abahussain al el., 2002)

Total population is about 5.7 million in 2004, including some 0.8 million non-Libyans. Of the total population only 13% is rural. Annual population growth for the period 1995-2000 is estimated at 2.2%. However, growth appears only in the urban areas, the rural population showing a negative growth of 1.3%. Average population density of about 3 inhabitants/km^2 varies between 150 inhabitants/km^2 in the northern regions to less than 1 inhabitant/km^2 elsewhere. In 1995, 54% of the Libyan population lived in the western coastal area (Jifara plain and Misratha area). The eastern coastal area (Al Jabalal Akhbar) is the second area of population concentration with 21%. This means that 75% of the population is concentrated over 1.5% of the total area of the country. In 2002, 72% of the population had access to improved drinking water sources (72% of the urban population and 68% of the rural population). About 97% of the urban population and 96% of the rural population had access to improved sanitation services (Countrywatch, 2000).

2.1.1 Location of the study area

The area selected for this study is located in the southwest of Tripoli in Libya specifically;

Longitude = 12°: 45\` to 13°E

Latitude = 32°: 45\` to 32°: 25\`N

Libya consists mostly of desert terrain. Only the narrow coastal strip receives sufficient rainfall to make it suitable for agriculture and this is where ninety three percent of the population lives. The coastal belt is where the main agricultural areas are also located. The area chosen for this study measures approximately 1600 km^2 and lies about 40 km southwest of Tripoli, (see figure 2.1).

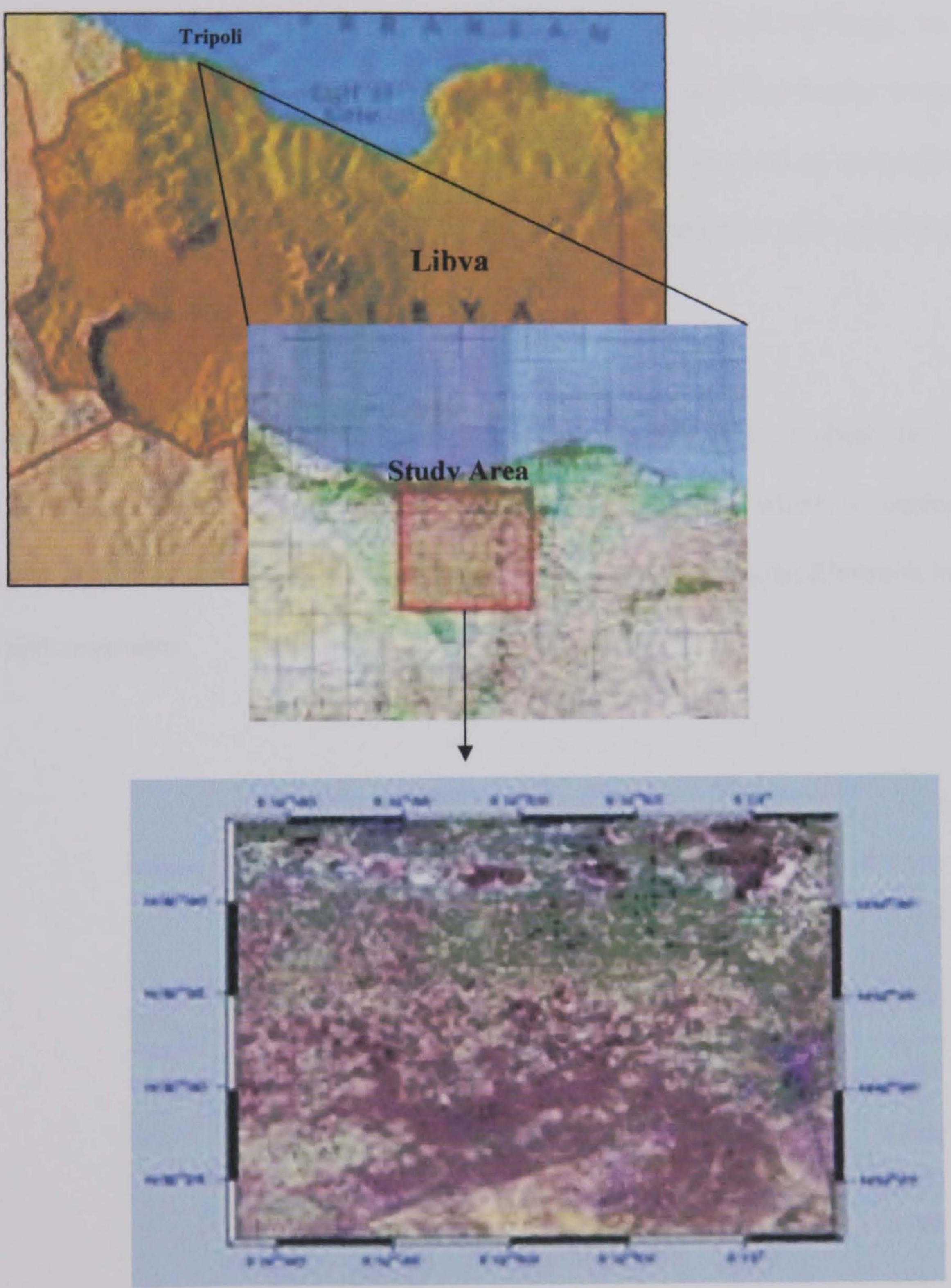


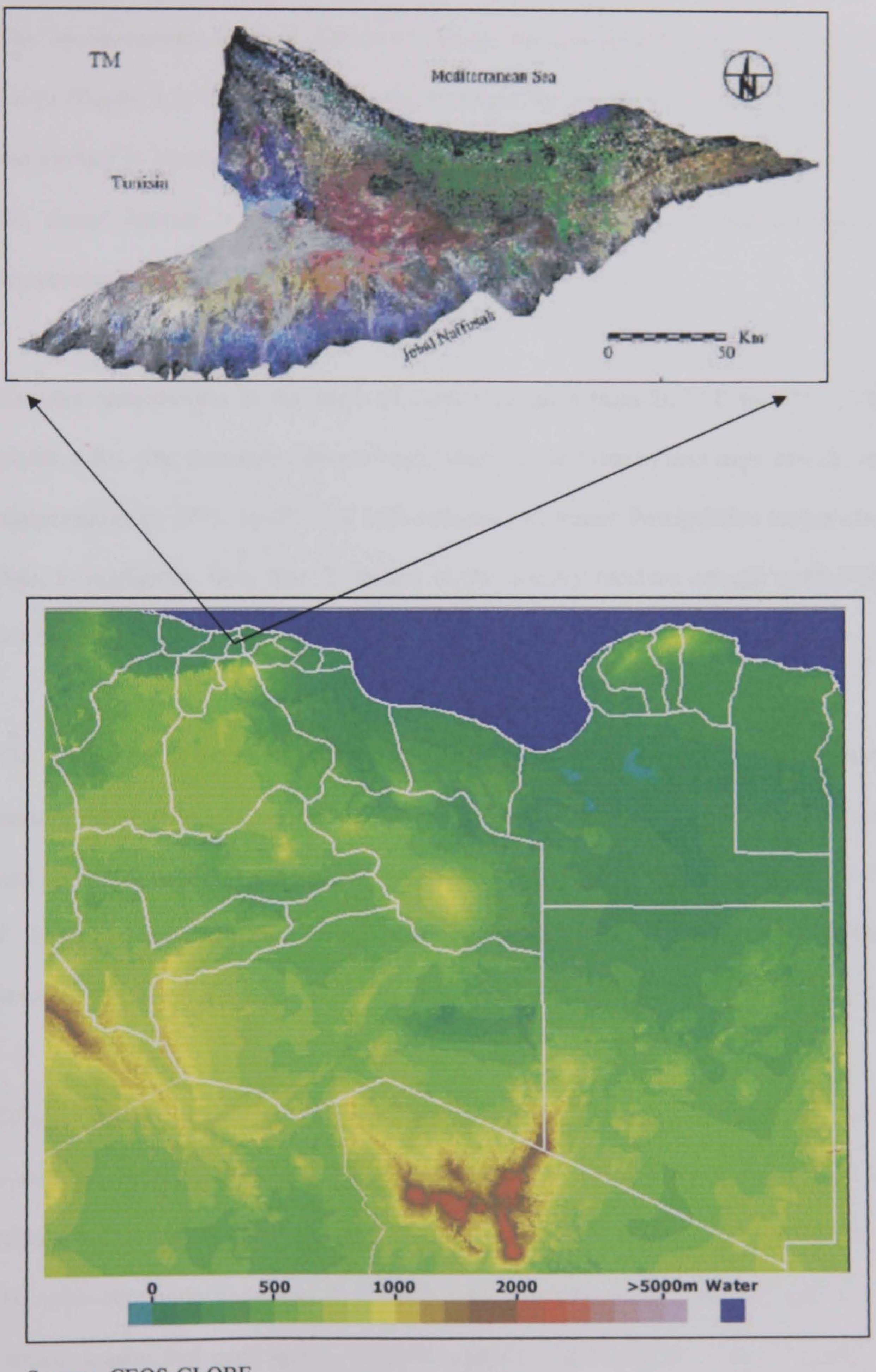
Figure 2.1. Location of the study area

2.2 Landforms

Landforms of Libya generally consist of barren plains in the north against plateaus and depressions in the south; the Mediterranean coast lands and the Sahara desert are the most prominent natural features. Though there are several highlands, no true mountain ranges exist except in the southern desert near the Chad border where the Tibesti Massif rises to over 3,000 m. Elsewhere a barren wasteland of rocky plateaus and sand occur which only allow minimal human habitation and agriculture is possible in a few scattered oases (McMorris, 1979).

The lowest point is Sebkhat Ghuzayil (47 m below sea- level), the highest one Bikku Bitti (2,267 m) above sea- level (CIA, 2004). The study area, which is considering part of Jifara plain, is an almost flat area. Figure 2.2 shows a Digital Elevation Model at 1km resolution.

Jifara plain include study area



Source: CEOS-GLOBE

Figure 2.2. Digital Elevation Model - 1km resolution

2.3.1 Climatic characteristics of Libya

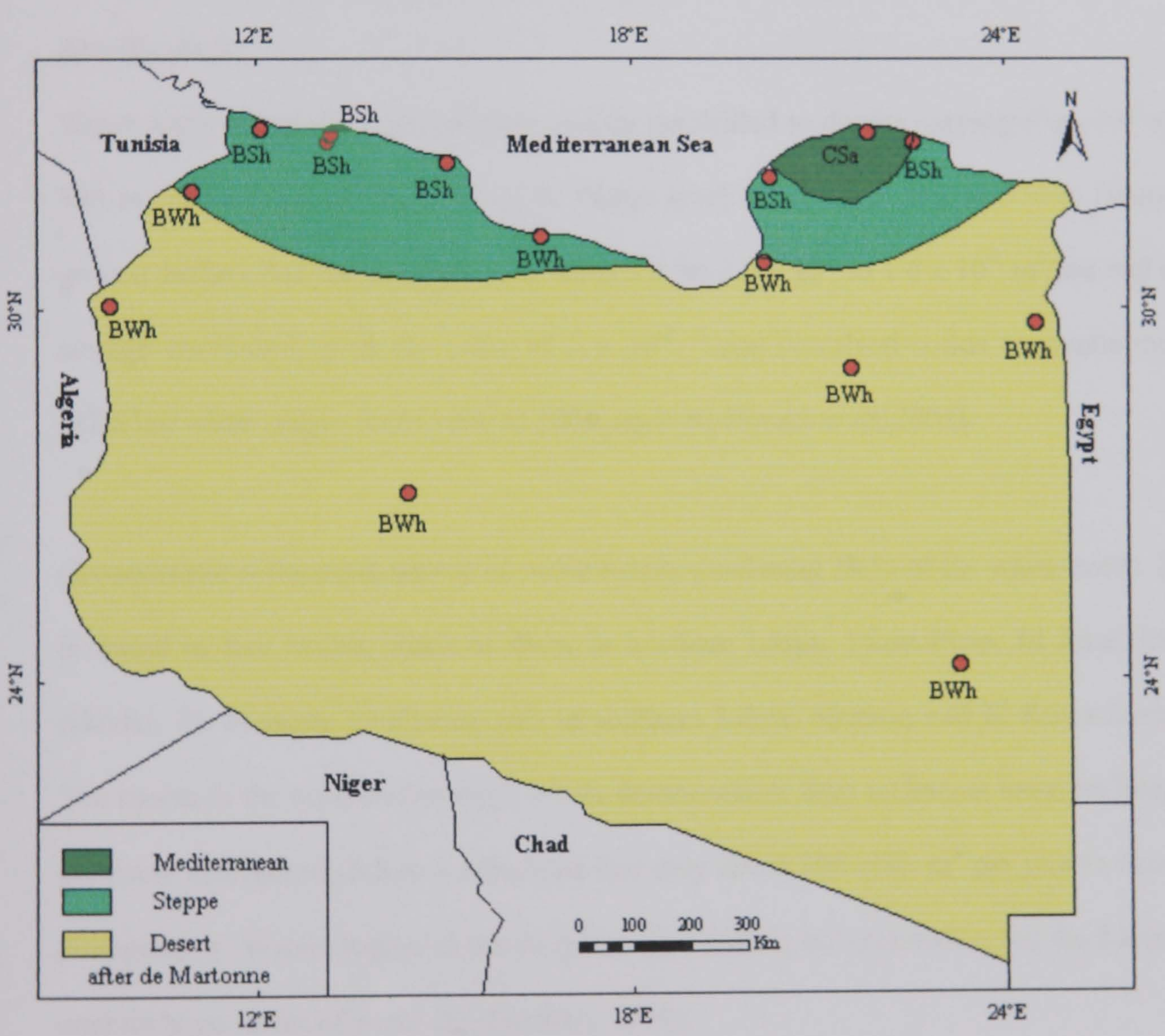
The Mediterranean Sea and Sahara Desert are the dominant climatic influences in Libya (Figure 2.3) In the coastal lowlands, where 80 percent of the population lives, the climate is Mediterranean, with warm summers and mild winters. The climate in the desert interior is characterized by very hot summers and extreme diurnal temperature ranges.

Summer temperatures in the north of Cyrenaica range from 26.7° C to 32° C. The *ghibli*, a hot, dry, dust-laden desert wind, which can last one to four days, can change temperatures by 17° C to 22° C in both summer and winter. Precipitation ranges from light to negligible. Less than 2 percent of the country receives enough rainfall for settled agriculture.

The Jabal areas of the north receive a yearly average of 381 to 508 millimetres. Other regions get less than 203 millimetres. Rain usually falls during a short winter period and frequently causes floods. Winters can be bitterly cold, with temperatures below 0° C. Frost and snowfalls sometimes occur in the mountains. Evaporation is high, and severe droughts are common.

Libya is vulnerable to climate change because of prevailing arid and semi-arid climate conditions, recurrent droughts, inequitable land distribution, and overdependence on rainfed agriculture. Precipitation is the main parameter of climate, which may control the socio-economic prospects. It begins usually in autumn to winter, which is the rainiest season and ends spring, while a negligible precipitation occurs in summer. High precipitation variability and severe precipitation intensities over Libya may

High precipitation variability and severe precipitation intensities over Libya may cause severe moisture stress on cultivated crops and reduce yields. As a common rule, precipitation in arid and semi-arid areas has in most cases negative effects. Due to high temperatures, most water evaporates without any benefit to agriculture, whereas only a small percentage of precipitation infiltrates to groundwater (El-Tantawi, 2003).



Source: Metrological Department

Figure 2.3. Climate map of Libya

2.4 Water resources

Al Aziziyah formation of middle-Upper Triassic outcrops at places near the surface south of Al Aziziyah fault overlying Abu Shaybah formation at the Jabal Nafusah foot. Its thickness varies between 150 to 350 m. It is composed of highly fractured dolomitic limestone intercalated with limestone, dolomite, marl and clay. The Al Aziziyah aquifer is well developed in the south central part and is exploited mainly for irrigation by local agricultural projects, such as Wadi al Hirah, Wadi al Hayy and Abu Shaybah.

Water wells penetrating Al Aziziyah aquifer are drilled to depths varying from 200 to 350 m with a yield of 50 to 90 m^3/h. Water level varies from 165 to 176 m below ground surface and the transmissivity ranges from 7.0×10^{-3} to 1.6×10^{-1} m^2/sec and a storage coefficient is in the order of 5×10^{-2}. Total dissolved solids concentration (TDS) of water ranges from 1500 to 2000 mg/l (El-Baruni *et al*, 2004).

Groundwater is the main source of water supply producing 88 % of the water needs. It is found in five basins, three of them in northern Libya: Jifara Plain, El Jebal El-Akhdar, El- Hamada El-Hamra, two in southern Libya: Murzuq and El-Kufra-Serir. The basins in the north suffer from severe deterioration; their recharges have not been precisely determined, but it is estimated that only about 500 mill. m^3 per year is from precipitation. Water storage of the basins in the south is not renewable, but the basins contain huge stores of water (El-Tantawi, 1998).

Tables 2.2 and 2.3 present the groundwater abstraction per area during the period 1975-2000. The total abstraction of 4,200 million m^3/year is about 8 times the annual renewable groundwater resources and therefore Libya depends heavily on fossil groundwater. The coastal aquifers are the only ones that are being recharged by rainfall, but uncontrolled groundwater development from these aquifers exceeds the annual replenishment. This has caused severe water level decline and seawater encroachment, which makes the coastal groundwater resources almost unusable because of their high salinity. The total water withdrawal of 4 268 million m^3, about 83% is used for agricultural purposes, 14% for domestic use and 3% for industrial use. More than 30% of the present domestic water demand is supplied by the GMRP [(1)]. Most of the industrial water is used in the oil industry (injection, processing and some domestic use (Aqostino, 2004).

[(1)] GMRP. The Great Man-Made River project to bring water from reservoirs in the southern part of Libya to irrigate northern coastal agricultural areas

Table 2.1: Total groundwater withdrawal in Libya from 1975-2000

Area	Water abstraction in million m^3/year					
	1975	1980	1985	1990	1995	2000
Al Jabal Al akdar	134	205	255	339	290	334
Al Kufra-As Sarir	224	295	487	526	560	575
Jifarah	567	600	780	860	1070	1060
Hamada El Hamra	132	299	418	413	417	405
Murzug	430	1055	1181	1306	1519	1754
Jabal Hasawna	0	0	0	0	0	140
Total	1487	2454	3121	3462	3855	4268

Table 2.2.Groundwater abstraction by area and sector objective in million m^3/year

Area	Domestic water supply**		Identified industrial water supply	Agriculture			Total
	Transport From GMRP*	Local Production		Agricultural projects	Private agricultural	Total	
Al Jabal Al Akdar	0	127	-	0	207	207	334
Al Kufra-As Sarir	94	12	117	204	148	352	575
Jifarah	0	140	-	0	920	920	1060
Hamada El Hamra	0	36	-	209	160	369	405
Murzug	0	58	0	271	1425	1696	1754
Jabal Hasawna	140	-	-	-	-	0	140
Total	234	373	117	684	2860	3544	4268

Source: FAO. 2005

*GMRP = Great Manmade River Project

**Domestic water supply includes 5-10 in million m^3/yr of water used for industry which cannot be identified

2.5 Soil

Soils in western Libya (from Tunisia to Misurata in the east) are: inceptisols and entisols (49.1 %), aridisols (11.5 %), salorthids (10.7 %) and sandy soils (3 %; UNEP, et al., 1996: 266). Sandy soils bear more developed vegetation with a more regular and higher primary productivity than finer textured soils. Thus, profitably and commercials cultivated rainfed olive orchards are grown on deep sandy soils under as little precipitation as 200 mm/year in Tripoli area, but this is not possible without an additional runoff complement on silt soils (Le Hou`erou, 2001: 108).

Soil salinization and alkalization occurs in the case of irrigated lands, with inadequate leaching of salts contained in the soil or added in irrigation water. Salinization and alkalization of soils prevail on the northwestern Jifara Plain where soils are converted to saline soils by the salinity of groundwater used for irrigation and the result of faulty technology in water development schemes such as using too salty water on too heavy soils and insufficient drainage or even no drainage at all (Le Hou`erou, 1977: 21).

Soil resources, survey reports and maps produced by various organisations differ in their contents, types of maps, scale of mapping, classification systems used, methods of soil analysis, and the criteria on which the interpretation of data is based. The major soil classification systems used in these reports are USA Soil Taxonomy, modern soil classification of Russia, French soil classification, and FAO/UNESCO system. The major available interpretive soil and land maps are land capability, soil salinity, soil erosion, soil depth, and soil and land suitability.

The Information systems, none of these maps are in digital format yet. Despite pressing needs for natural resources management in The Libyan Arab Jamahiriya, the necessary Land Resource Information Management System (LRIMS) is still lacking. This has recently (September 2000) promoted urgent calls for the establishment of a Libyan land resources database and Information Management System through project LIB/00/004, implemented by FAO. This project will insert all natural resources data in a geographically referenced computerized database.

2.6 Vegetation

The arid steppes of northern Africa are chiefly of a secondary nature, originating from a pristine xerophilous open forest and woodland through an over-grazing process which affects both soil and vegetation, via the nature and distribution of the organic matter in the soil profile. As a matter of fact, about 50 % of the steppes have been cleared for cultivation over the past 80 years (Le Hou`erou, 2001: 126).

The thinning and death of vegetation in the dry season increases the extent of bare ground. This is followed, in turn, by a deterioration of the surface conditions that are vital to plant growth. Practices such as shifting cultivation, bush burning or overgrazing have been very destructive to the flora, and it is often difficult to distinguish between primary and secondary growth.

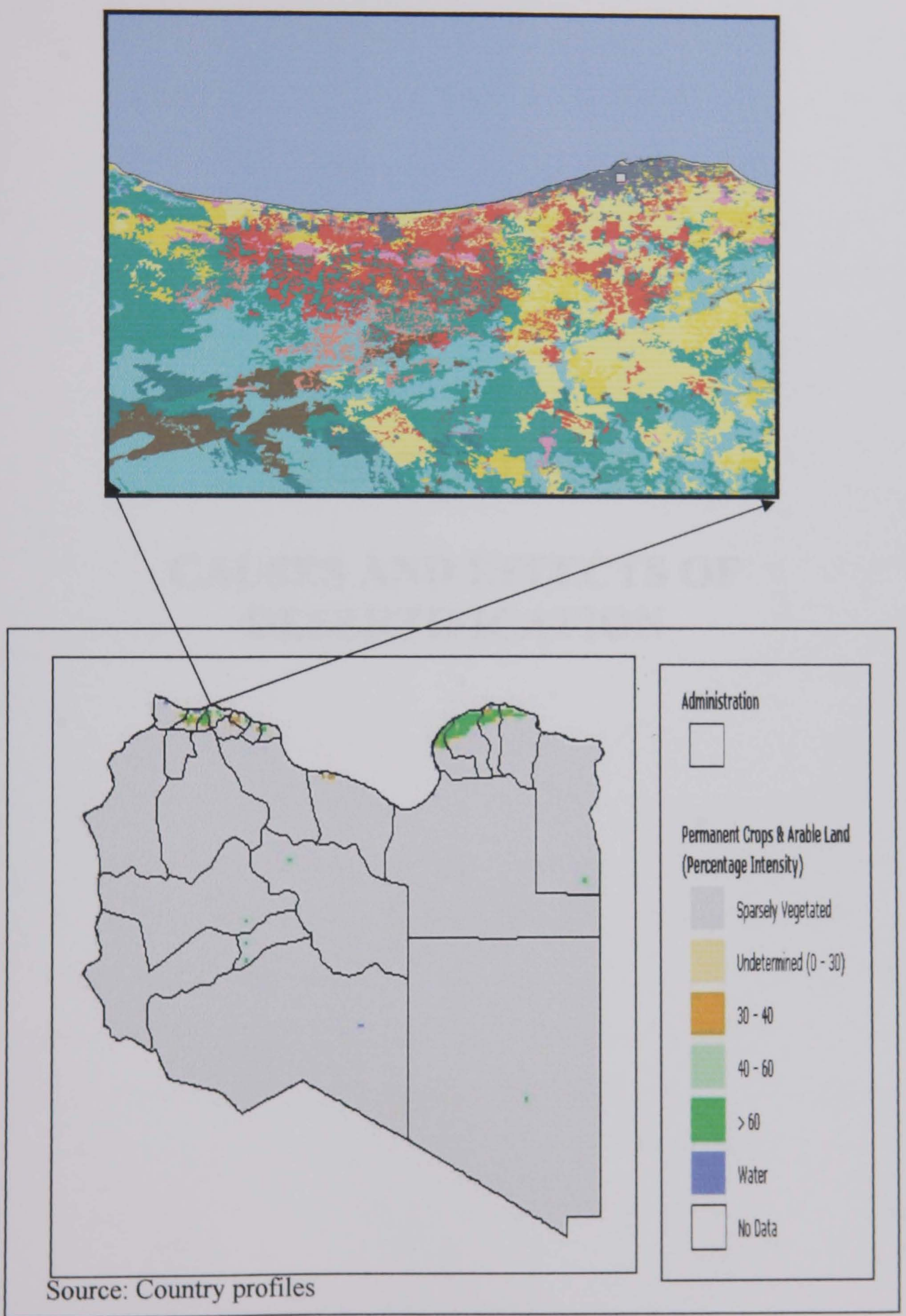


Figure 2.4- Vegetation land cover map

CHAPTER THREE

CAUSES AND EFFECTS OF DESERTIFICATION

3.1 Introduction

The current environmental limitations in Libya are attributable to the elements of the desert climate, which played a substantial role in determining land uses and in forming the sensitive water balance rarely achieved in most areas owing to the fluctuating rainfall averages and seasonal rainfall variations, the quantity of water available annually being estimated at about four billion cubic meters. Under the effect of these limitations, the various drought factors produced specific chemical properties and soil, which is naturally and characteristically fragile. The agricultural land base was therefore limited to not more than 2 percent of the country's total area. Moreover, these factors had implications for the composition and distribution of the natural plant cover, which produces enough to satisfy only a modest 35 per cent of animal food requirements (UNCCD, 1999).

Success in combating desertification will require an improved understanding of its causes and impacts and especially the linkages between desertification and climate, soils, water, land cover and socio-economic factors. 90% of Libya can be regarded as vulnerable to desertification. These areas are almost exclusively used as rangelands.

3.2 Definition of desertification

The word *Desertification*, from an etymological point of view, is derived from Latin: on the one hand, "*desert*", with a twofold origin: (1) the adjective *desertus*, that means *uninhabited*, and (2) the noun *desertum*, that means *a desert area*; and on the other hand, "*fication*", that refers to the act of doing (Mainguet, 1999).

According to the United Nations Convention to Combat Desertification (UNCCD 1994), "desertification' means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities." Land degradation, in turn, is a reduction in the biological and economic productivity of terrestrial ecosystems, including soils, vegetation, other biota, and the ecological, biogeochemical and hydrological processes that operate therein (Reynold, 2001).

Several other concepts are important in studying land degradation and desertification: *sustainability* or the ability of the land to remain productive over long time periods; *resilience* or that quality of a resource that makes it sustainable or resistant to degradation; *vulnerability* or the risk of specific adverse outcomes for people or ecosystems in the face of different stresses; and *carrying capacity* or the number of people and animals the land can normally support without being significantly stressed.

Many conferences have been held to investigate the desertification process (e.g. United Nations Conference on Desertification (UNCOD) Nairobi 1977), The Ad-Hoc Consultative Meeting on Assessment of Global Desertification: status and methodologies, February 1990, UNEP- Nairobi and international conferences held (October 1994 and May 1997) in Tucson, Arizona, USA, in support of (UNCCD) United Nations Conventions to Combat Desertification). These conferences raised the world's awareness to the effects and causes of desertification and provided programs of action for sustainable development and to combat desertification The increasing rate of desertification on a global scale is one of the most pressing concerns among environmental scientists and laymen since it implies a clear manifestation of climatic change processes and human interaction on the environment (Collado *et al.*, 2002).

Desertification has been widely represented in the media and discussed by politicians, and has been seen as a major cause of human problems. By the UNEP classification system, 41% of the Earth's land area is hyper-arid, arid, and semi-arid or dry sub-humid (UNEP, 1992). UNEP estimated that 69% of the drylands, excluding the hyper-arid deserts, were already moderately to severely degraded by 1992 (Dregne *et al.*, 1991). Of the more than 900 million inhabitants of drylands 135 million are considered at risk of collapse of their traditional land-use systems and episodic mass starvation continues to be a problem in Africa (Lean, 1998).

3.3 General factors causing desertification

The causes leading the land to be desertified may be of varied description, but there are two most important factors that can be recognized called 'natural factor' and 'human factor'. The combining actions of those factors are the major causes for sandy desertification, and the human factor is more important than the natural one (Wang Tao, 1998)

Desertification is the resultant consequences of natural and human factors. Natural factors include the climatic changes, unequal distribution of precipitation at different seasons and regions. Human factors comprise overcultivation, overgrazing, deforestation and poor irrigation practices. At the same time, these unsustainable activities are related to population growth and economic development,

3.3.1 Natural factors causing desertification

3.3.1.1 Vegetation degradation

Degradation of vegetation occurs in the early stages of the desertification process, e.g. when deforestation makes soil more susceptible to wind and water erosion, but it also continues later in response to the decline in soil fertility and structure that follows overcultivation, overgrazing and poor irrigation management. The vegetative cover of an area may be said to be degraded when it becomes inferior to: (a) what the land could be expected to support, taking into account the climate, site conditions and historical experience; (b) what the area needs for the purposes of environmental protection. (Arnold, 2001).

Vegetation is the buffer between soil surface and the processes that can cause degradation by soil displacement. Once vegetation of various types has been removed, several factors come into play in destroying the soil mantle, which is the precursor to desertification. The extent of degradation of vegetation followed by degradation of natural resources in general is of great concern and has a direct implication to the development and livelihood of mankind. It is estimated that some 1,035 million ha or 20% of the Earth's arid zones, arising from serious degradation of vegetation cover, are affected by human-induced soil degradation. Of this 45% is caused by water erosion, 42% by wind erosion, 10% by chemical impacts and 3% by physical destruction of the soil structure (Horstmann, 2002).

3.3.1.2 Soil degradation

Soil degradation is defined by FAO/UNEP/UNESCO (1979) as "a process which lowers the current and/or the potential capability of soil to produce (quantitatively and/or qualitatively) goods or services. Soil degradation is not necessarily continuous. It may take place over a relatively short period between two states of ecological equilibrium". The processes of soil degradation are mainly water erosion, wind erosion, salinisation and/ or sodification, chemical degradation, physical degradation and biological degradation. Soil degradation is considered as the most critical component of land degradation and, in the framework of irreversible land degradation, as the main factor in desertification (Mainguet, 1994)

The major soil degradation processes in the African dry zones are wind erosion (52%) followed by water erosion (30%), loss of chemical nutrients and salinisation (10%) and physical (8%) degradation. Waterlogging plays only a small role in soil degradation of the semi-arid area. Erosion by wind is more prominent in the arid areas while it has about the same effect in the semi-arid zone. Due to the high population of livestock in the semi-arid zone, soil compaction is greater here than in the other dry zones. Some 480.5 million ha of drylands in Africa are thus exposed to degradation by wind and water erosion in addition to loss of nutrients, physical compaction and to a less extent waterlogging. (Chikamal and Kigomo, 2001)

3.3.2 Human factors causing desertification

3.3.2.1 direct factors

Land management practices and land use changes leading to overgrazing, deforestation forest fires, overexploitation of water resources, and secondary salinisation are among the most recognized causes of land degradation and desertification (Victor, 2004).

3.3.2.1.1 Overcultivation

Overcultivation occurs when farmers try to crop the land more intensively than permitted by its natural fertility, and fail to compensate for the export of nutrients in the crop by using artificial fertilizers or fallowing the land so that its fertility can regenerate naturally. Overcultivation therefore reduces the fertility of the soil, damages its structure, and exposes it to erosion. In dryland areas it is often caused by the breakdown of traditional rainfed cropping systems, either by outside pressures or because they are unable to produce enough food to sustain high population densities (Dong, 2002).

3.3.2.1.2 Overgrazing

Overgrazing is another cause of land degradation. Because of increasing demographic pressure, livestock numbers have not decreased on average, even when the space left for grazing has decreased due to cultivation. In addition to the potential extinction of threatened species and the development of persistent exotic species, overgrazing has led to a reduction in vegetation cover for vivacious species and opened the door to land degradation (Kassas, 1995).

Overgrazing is indeed a major cause of desertification, and rangelands account for almost 90% of desertified lands, but the syndrome is not quite as simple as was first thought, since desertification takes place throughout the drylands, not just on the edge of the desert (Alan, 1982).

One of the important factors causing desertification is excessive grazing. Rapid population increases in developing countries can create serious food shortages. Furthermore, when goods are distributed more widely, and the market principle begins to operate, people begin to pursue a more comfortable lifestyle. Inevitably, the number of livestock increases, and the livestock in turn eat the grass, even to the point of eradicating it. In the natural course of things, even if livestock were to consume all the grass, new sprouts would grow, and the grassland would be restored. However, because the number of livestock released for grazing exceeds the ability of land to restore itself, all the greenery is consumed to the point of eradication. When that happens, it becomes very hard for any vegetation to grow back, and the land is ruined.

Then more forests are cut down in order to open up more ranches and pastures. This leads to a vicious cycle, and an ever-increasing area of land becomes desert.

3.3.2.1.3 Deforestation

Over the last 200 years, deforestation increased because the timber industry became a globally profitable endeavor so that clearing of forests was accelerated for the purposes of industrial development. In the long term, this intensified deforestation is considered to be a serious challenge because the forest is unable to regenerate itself quickly (Countrywatch; 2000). Deforestation, caused by the forest fires, is a leading factor contributing to soil degradation. The determination of the areas with low potential for natural regeneration and high risk of soil erosion and thus of serious desertification threat, is of critical importance for reliable and effective decision making for the protection of forest environment (Rokos and Kolokoussis, 1993).

Fuelwood is the predominant forest product used in the drylands. However hot the days may be, the nights are cold, and wood is needed to provide warmth and to cook the evening meal. Half of all the wood used in the World is burned as fuel, mainly in developing nations where it accounts for four-fifths of wood harvested. About 90% of people in developing countries depend upon wood or charcoal as their main source of household fuel. Traditionally fuel wood has been gathered from dead wood but now the wholesale cutting of trees for fuel wood is an important cause of deforestation. Those trees that remain are often key sources of animal fodder, which is either cut from them by herders or directly browsed by livestock. Browsing can sometimes even kill a tree, especially when degraded rangelands provide inadequate food for animals. Too much browsing changes the species composition of woodlands so that less palatable species become dominant. (Dong, 2002)

3.3.2.1.4 Poor irrigation management

Poor soil and water management, including insufficient water application, irrigation with saline/sodic waters water without proper agronomic practices, have been identified as being the main drivers of salinisation/sodification in several salinity projects (Victor, 2004).

An increase in irrigated cropping might seem to be the logical way to solve the food problems of dryland areas. Using water from rivers flowing through the drylands or from underground aquifers, irrigated cropping is supposedly independent of the cyclical variations in rainfall, and the threat of crop failure during droughts is therefore removed. Watering crops can indeed increase the yield of cereals sixfold and the yield of root crops fivefold. By producing large yields on relatively small areas of cropland it can in principle allow agricultural production to keep pace with the needs of rapidly growing populations, and help to stem the vicious circle of desertification in which the area of (often marginal) land under cultivation has to be continually increased to compensate for falling yields caused by poor farming practices (Grainger, 1991).

3.3.2.2 indirect factors

The above mentioned factors define the growth of desertification in terms of the four main direct causes- Overcultivation; overgrazing; deforestation and mismanagement of irrigated cropland. At the same time, poor land use is accelerated by drought, and is also greatly influenced by various underlying social, economic and political factors. Population growth and economic development are the two main driving forces which lead to an expansion of agriculture and to changes in the types of agriculture practiced. Economic development is also generally accompanied by a growth in urban populations, and serious degradation of natural resources is common around towns and cities. The benefits of economic development are not shared equally among the inhabitants of a country, and it is often the poorer people, forced to live on the worst lands, who are the most directly involved in causing desertification, the most seriously affected by it, and the least able to prevent it from happening. They are also often affected by famine, although that is not an inevitable consequence of drought or desertification, and can occur when government policies constrain food production in particular areas and fail to alleviate poverty.

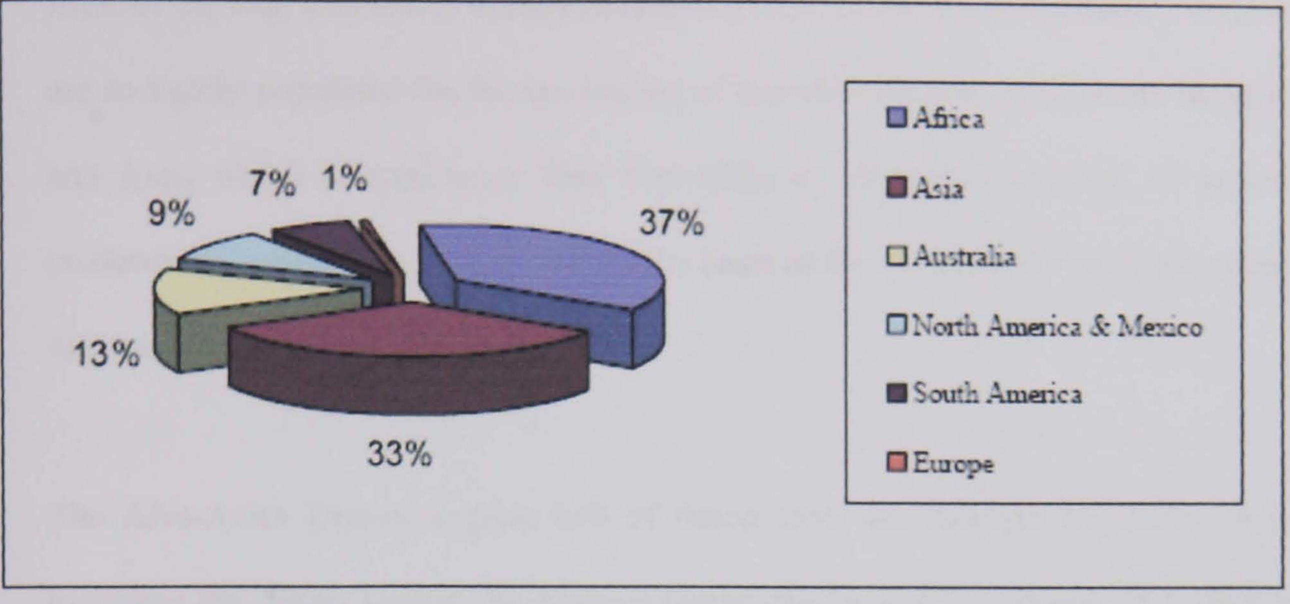
3.4.2.2.1 Population growth

Population growth does not necessarily result in desertification, but can help to induce it if the only way to increase food production is to increase the area being cropped yields per hectare can be increased by more intensive cropping, but these can only be sustained through investment in fertilizers and more productive cropping systems. Many developing countries have insufficient capital to invest in agriculture and, without fertilizers to replenish nutrients taken from the soil, more intensive cropping leads to declining fertility and falling yields (Dong, 2002).

3.3 The distribution of drylands in the world

The World's drylands are mainly found in two belts approximately centered around the Tropics of Cancer and Capricorn (23.5 north and south of the Equator respectively), although the width of each belt in degrees of latitude can be quite large. Drylands constitute almost all of the northern half of Africa, southwest Africa, the Middle East, parts of India and Pakistan, Mexico, North America, the western coast and southern tip of South America, and a large part of Australia. Many of these regions are dry as a result of global patterns of atmospheric circulation. Warm air rises at the Equator and then moves towards the cooler Poles to redistribute the

Figure 3.1: The Distribution of Drylands by Region.



Source: Grainger (1991)

surplus of solar energy received at the Equator. As part of this process the two sets of air currents subside slightly to the poleward side of the two Tropics at about latitude 30. For rain to form, warm moist air has to rise from the ground and be condensed to water in the cool upper atmosphere. Since air in the vicinity of the subtropics is subsiding rather than rising, however, these regions receive relatively little rain. The drylands cover more than a third of the earth's land surface, but are not evenly distributed (Figure 3.1).

More than 80% of their total area is found in just three continents: Africa (37%), Asia (33%) and Australia (13%). In contrast, the shares of North America and Mexico, South America and Europe are 9%, 7% and 1% respectively. Africa, Asia and Australia account for fifty-five of the sixty-six countries affected by aridity in some way and for all the thirty-four countries with 75-100% of their national land area arid or semi-arid (Table 3.2). Of these thirty-four countries, eighteen are in Africa, fourteen in West Asia (the Middle East), one (Pakistan) in South Asia, and the remaining country is Australia. Africa, Asia and Australia also account for about four-fifths of the total area that is at least moderately desertified. Since Australia's drylands are so lightly populated the human impact of desertification is most severe in Africa and Asia, which contain more than four-fifths of all people affected by at least moderate desertification (Table 3.1). At the heart of the drylands are five major zones of natural desert (Dov and Arnold, 2001):

The Afro-Asian Desert, a great belt of desert from the Atlantic Ocean to China, including the Sahara Desert, the Arabian Desert, the Iranian Desert and the Touranian Desert in the southwest USSR (which includes the Kara Kum and Kyzyl Kum Deserts), the Thar Desert in Pakistan and India, and the Takla Makan and Gobi Deserts in China and Mongolia;

The North American Desert of the southwest United States and northwest Mexico, comprising the Great Basin, Mojave, Sonoran and Chihuahuan Deserts; The Atacama Desert, a thin coastal strip between the Andes and Pacific Ocean, running from southern Ecuador to central Chile; and the Patagonian Desert in Argentina to the east of the Andes; The Namibia and Kalahari Deserts in southwestern Africa; The Australian Desert.

Land on the desert fringe could in theory be desertified in various ways. First, desert sands could be carried on to adjacent land by winds, without any human involvement. Second, short term adverse climatic conditions, such as drought, could lead to overcultivation, overgrazing and the consequent degradation of drylands on the fringes of deserts. These degraded lands could later be overrun by sand blown from the adjacent desert. Human impact is the dominant in this mechanism, but is influenced by climate. Third, the short-term adverse climatic conditions could become so prolonged that a long-term reduction in rainfall occurs and, even without any human involvement, areas which were previously arid would become hyper-arid and in time take on the ecological characteristics of natural deserts. In practice the change in climate would also probably lead to intensified land use and consequent degradation, and so the roles of human impact and climate would again overlap (Alan, 1982).

Table 3.1 Areas and numbers of people affected by moderate desertification by region

	Affected area (1,000 sq km)	% Total	Affected population (Millions)	% Total
Africa	7,409	37	108.00	38
Asia	7,480	37	123.00	44
Australia	1,123	6	0.23	0
Med, Europe	296	1	16.50	6
N. America	2,080	10	4.50	2
S. America & Mexico	1,620	9	29.00	10
Total	20,008	100	281.23	100

Group	Description	Number	Percent of arid/semi-arid Land in Nation	Countries
1	Arid	11	100	Bahrain, Djibouti, Egypt, Kuwait, Mauritania, Oman, Qatar, United Arab Emirates, Saudi Arabia, Somalia, South Yemen
2	Predominantly Arid	23	75-99	Afghanistan, Algeria, Australia, Botswana, Burkina Faso, Cape Verde, Chad, Iran, Israel, Jordan, Kenya, Libya, Mali, Morocco, Namibia, Niger, North Yemen, Pakistan, Senegal, Sudan, Syria, Tunisia
3	Substantial Arid	5	50-74	Argentina, Ethiopia, Mongolia, South Africa, Turkey
4	Semi-arid	9	25-49	Angola, Bolivia, Chile, China, India. Mexico, Tanzania, Togo. USA
5	Peripherally Arid	18	<25	Benin, Brazil, Canada, Central African Republic, Ecuador, Ghana, Lebanon, Lesotho, Madagascar, Mozambique, Nigeria, Paraguay, Peru, Sri Lanka, USSR, Venezuela, Zambia, Zimbabwe

Table 3.2. Distribution of drylands by country Source: Grainger (1991)

3.5 Desertification in the Arabic Region

The Arab Region covers an area of 14.2 million km^2 or about 10.2% of the World extending from Iraq in the north to Somalia in the south and from Mauritania in the west to Oman in the east. It extends between longitudes of 17° and 60° east and between latitudes of 11° 30 and 37° 30° north. Such an area with wide latitudinal differences has different environmental conditions in its various parts. Extremely arid,

arid, semi-arid and dry sub-humid areas cover about 90% of the Arab Region. These are characterized by great variability in both seasonal and annual precipitation, which is the most important climatic feature of the dryland ecosystems. Unreliable rainfall and unfertile soils make the major land uses, agriculture, forestry and range management, marginal on any given site in any of the countries of the Region. About 52% of the area receives an average annual rainfall of less than 100mm, while 15% receives 100–300 mm, and 18% receives more than 300mm (Table 3.3). This amount increases to reach 1500mm of rainfall in parts of the region, e.g., highlands of Lebanon, Syria, North Africa and along the coastal areas and southern Sudan. Total rainwater amounts to 0.04 billion-m^3 yr^{-1} ($Bcmyr^{-1}$) in Bahrain and reaches 1169.8 in Sudan, totaling 2545.5 $Bcmyr^{-1}$ in the region (ACSAD, 1996).

Historically, there has been a long and well-established relationship between the desert's marginal resources and the population of the region. These lands were the main source for cereal and animal production. Communities in the Arab Region have throughout the recorded history (last 12,000 years) developed indigenous tools, technologies and regulations to protect and improve their land and water resources. Their efforts kept a balanced and sustainable use of these resources to meet their needs for food and feed. However, when the demand on land and water resources exceeded their carrying capacities, land degradation has become an increasingly limiting factor to land's productivity. The effects of desertification were and still are amplified, as these fragile eco-systems are at- or near-their limits of resilience (Batanouny, 1998).

Table 3.3 Rainfall Distributions in the Arab Region

Climatic division	Area % Of the total	Amount of rainfall received % of the total
1. Desert (Less than 100 mm)	52	14.1
2. Semi-desert (100-300)	30	28.6
3. Sub-tropical/Sub-humid (300-500)	7	15
4. Mediterranean/humid tropical (500-800)	5.5	15.3
5. Equatorial (More than 800mm)	5.5	27

Source: ACSAD (1997) with modifications.

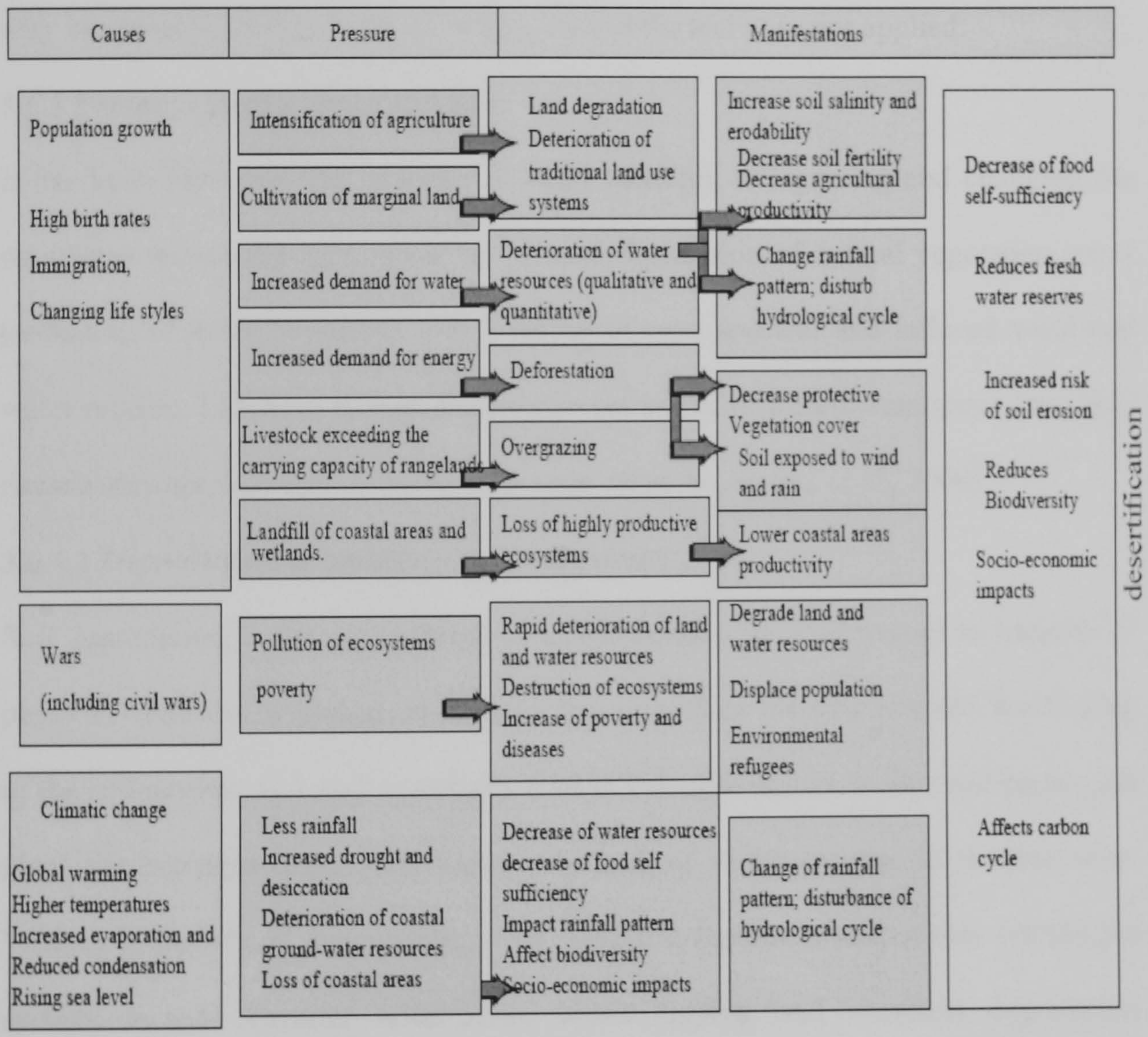
Information about desertification in the Arab Region is not quantitative. Available information indicates that most of the land resources in the Arab Region are either desertified or vulnerable to desertification, the major driving forces causing desertification in the Arab Region, their impacts and manifestations are summerized in Fig. 3.2, thus affecting food security and development in the region. In total, 88.4% of the total area is desertified or vulnerable to desertification (Shakhatra, 1987). Recently, Abdelgawad (1997) estimated the total areas desertified and vulnerable to desertification as 9.84 million km^2 or about 86.7% of the total area of the Arab Region. The main forms of desertification prevailing in the Arab Region are:

(1) Wind erosion: This is considered the most common environmental problem in the Arab Region leading to

(2) Loss by removal of the fertile topsoils.

(3) Encroachment and accumulation of sands on productive rangelands and agricultural land, urban areas and civil construction (infrastructure).

Figure (3.2); Major driving forces for desertification in the Arab Region and their impacts.



Source; (Asma. A. Abahussain, *el, al,* 2002)

3.6 Desertification in Libya

Desertification as previously defined can only occur on land prone to desertification processes. Land vulnerability to desertification is determined by current climate, relief and the state of the soil and natural vegetation. Human activities are the main factors triggering desertification processes on vulnerable land. These activities are many and vary by country, society, land use strategies and the technologies applied.

3.6.1 Factors causing desertification

It has been indicated that scarcity of water (aridity), overgrazing and changing the rangeland to rain-fed agriculture had caused destruction of natural vegetation cover (reduction of bio-productivity and invasion of new species) and induced wind and water erosion. Increased human pressure on the use of localized underground aquifers caused seawater intrusion in the coastal zone. (Ben-Mahmoud *et al.*, 2000)

3.6.1.1 Desertification caused by natural factors

Soil degradation is the main threat of desertification, it is subjected to hazards of physical, chemical or biological changes that undermine the structure and functioning of the soil system, and may eventually lead to a decline in soil quality and permanent plant life becomes impossible, because of lack of water reserves in shallow soils. Various forms of soil degradation, often related to landuse practices that overtax the system, include erosion, salinization, water logging and chemical degradation (Kassas, 1987: 391). The major soil problems of Libyan agriculture are erosion and salinity. The most dominant soil-degradation process in Jifara Plain is erosion; the potential for erosion generally increases under arid and semi- arid climates where high intensities of precipitation and windstorms prevail (El-Tantawi, 1998).

- **Vegetation degradation,** in recent decades, a large area of vegetation was cleared in Jifara Pain (figure 3.3) wheat or barley cultivation. In pastoral rangelands, there is an initial deterioration in the composition of pastures, which are subjected to excessive grazing in dry periods. The study area has been significantly degraded in quantity and quality of vegetation (See appendix D). Vegetation destruction takes place by overgrazing and over cultivation, both activities being driven by the needs of a rapidly growing population.

Figure 3.3. Vegetation destruction in the study area

3.6.1.2 Desertification caused by human factors

Human activities that cause desertification in Libya are mainly: Agricultural encroachment and cultivation of soils that are fragile, or exposed to erosion by wind or water; Overgrazing - often selectively - of shrubs, herbs and grasses; Deforestation and overexploitation of woody resources, in particular for fuelwood and charcoal; Uncontrolled use of fire for agricultural and forest clearing; Unsustainable agricultural practices; Poor irrigation practices and inefficient water use; Chaotic urban sprawl on fertile lands and forests; Pollution, solid waste dumping, wastewater effluents, industrial wastes (El-Tantawi, 1998). Human factors can be contributed by;

Deforestation for agriculture in semi-arid lands around settlement areas is the main cause of land degradation in the areas around Tripoli. The destruction of forests around Tripoli city is shown during a 7-year period 1986-1993 (Fig. 3.4 and Tab. 3.4).

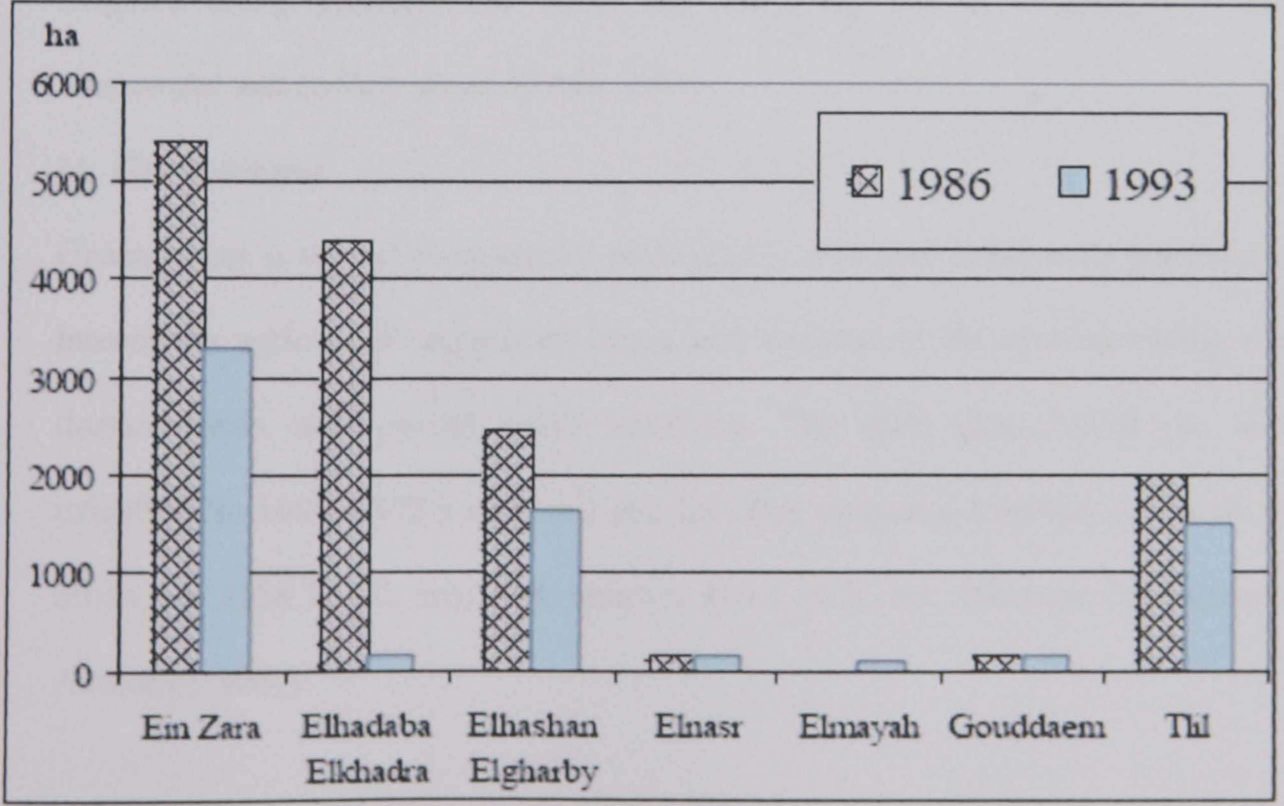


Fig. 3.4: change in forest cover around Tripoli city between 1986 and 1993 (ha).
Data source: Kredegh, 2002: 47

Area	1986	1993	Deterioration
Ein Zara	5,412.0	3,298.0	2,114.0
Elhadaba Elkhadra	4,397.0	169.2	4.227.8
Elhashan Elgharby	2,467.0	1,643.2	823.8
Elnaser	155.6	155.6	0
Elmayah	104.6	104.6	0
Gouddaen	170.4	170.4	0
Tilil	2,000.0	1.500.0	500.0

Table 3.4: Deforestation around Tripoli city in northern Jifara Plain between 1986 and 1993, (ha)
Source: Kredegh, 2002: 47

a) Poor management

In Libya, the total water managed area is approximately 470 000 ha, all equipped for full or partial control irrigation. On almost the entire area, sprinkler irrigation is practiced, because of the sandy soils prevailing in most areas of Libya. About 99% is irrigated using groundwater, while the remaining 1% is irrigated by treated wastewater and surface water. (FAO, 2002)

b) Groundwater

Groundwater is subject to excessive mining as it is located in the most populous and intensively agricultural region of Libya and because of its ever-increasing water demand from underground water resources. The main groundwater use is for irrigation (in 1998 1,472.5 mill. m^3) and for other purposes: livestock (4.3-mill. m^3), urban use (188.1-mill. m3) and industry (10.1 mill. m3; (General Environmental Authority, 2000).

c) Population

The Jifara Plain is heavily populated, mostly along the Mediterranean coast; it embraces. Tripoli city, capital of Libya and some of the important towns such as: Zuara, Al-Zawia, El-Azizia, Surman, Sebrata, Qasr Al-Qarabulli, and Bin-Ghashir. These settlement centres are subject to expansion as a result of population growth and migration. Built-up areas of Tripoli city have increased from 8,011.4 ha in 1966 to 19,236 ha in 2000 (El-Zannan, 2000: 84; Fig. 3.5).

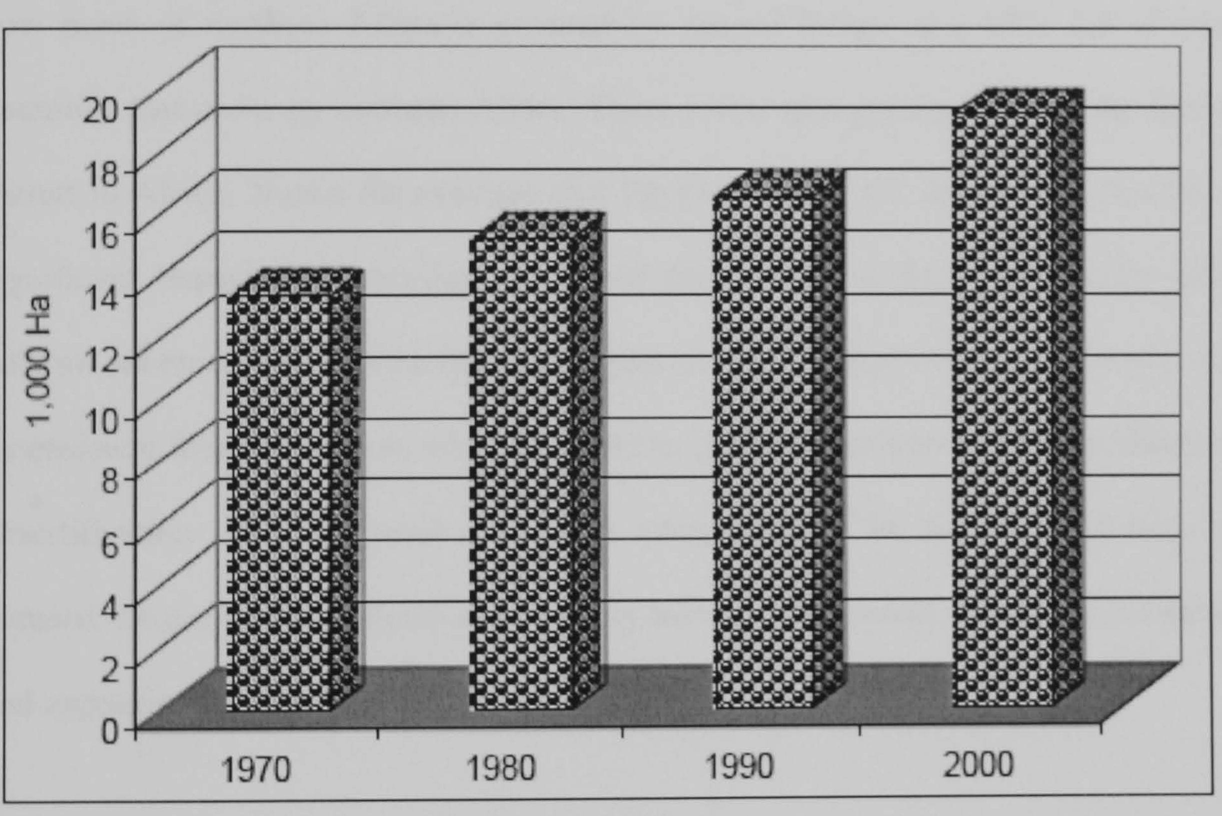


Figure 3.5: Built-up area expansion of Tripoli city between 1970 and 2000.
Data source: El-Zannan, 2000: 84

The following summarises the main causes of desertification in Libya:

- Destruction of vegetation caused by undue collection of fuelwood on sand plains or vegetated dune areas.
- Destruction of vegetation caused by technologic factors on the sand surface and the blowing of the underlying sand source.
- Over-cultivation or crop development on sandy surfaces.

- Misuse of water resources
- Over-utilization or poor exploitation of underground water resources

3.7 Effects of Desertification

The Sahara of Africa, measuring between ~7,000,000 and ~9,000,000 Km^2 in area, is allegedly expanding southward. This data was recorded from satellite used to determine annual variation of land from 1980 to 1990. The movement has been attributed in part to climate variation, but mostly in part to land mismanagement. So how much of northern Africa is covered by desert? Below is a table 3.5 of most countries that make up northern Africa. These make up a good portion of the Sahara Desert in Africa. Notice for example that Egypt is nearly 1/3 desertified. This has a significant impact on agriculture and food distribution in Egypt and many other African countries. The contraction and expansion of the desert causes many years of inconsistent food production, which has lead to sickness and starvation. The effects of desertification are widespread and cause many changes in the land and lives of humans. Desertification effects almost every human in the world directly or indirectly and approximately one third of the earth's land surface. (Dustin *el al*, 2000)

Table 3.5 the countries that make up northern Africa

Country	Total Area Desert (1000Ha)	% Desertification
Algeria	338	15
Chad	7	15
Egypt	2,486	30
Ethiopia	94	6
Libya	234	24
Mali	350	10
Morocco	525	10
Niger	14	7
Sudan	1,700	21

Over 45% of Africa is affected by desertification, while 55% is at high-to-very-high risk of erosion (UNEP 2003). Desertification is compounded by the other major environmental concern of deforestation. In fact, studies have shown that mortality rate, maternal health, and girl child education in the region are directly linked to environmental changes such as deforestation. In rural areas, households rely on females to fetch firewood, therefore, continued deforestation implies longer walking distances for women and girls. These result in complications in pregnancy, other ailments, as well as less time for girls to do school work. Studies have also shown that women and girls in Africa spend an average of three hours a day fetching water, hence expending more than a third of their daily intake of food (UNDP, 2003).

3.8 Conclusions

This chapter discussed desertification in general as a phenomenon, with particular reference to Libya. There are two major areas in Libya that suffer from severe desertification. The first is the coastal plains known for their moving sands which pose a threat to agricultural land, towns and roads and which expose the areas to soil erosion and salinisation problems. The second is the mountains, which extend all over the country and are exposed to soil erosion and degradation.

According to UNEP and other UN desertification assessment criteria and related maps, desertification in Libya is caused mainly by harsh climate conditions, misuse of vegetation cover, exhaustion of water resources, and non-compliance with proper agricultural instructions. Other reasons include the fragile and sensitive nature of the terrain and prevailing socioeconomic conditions. These various factors will be described in some detail in the next chapter together with ways of monitoring them using remote sensing technology.

CHAPTER FOUR

MONITORING STUDYING OF REMOTE SENSING FOR DESERT ENVIROMENTS

4.1 Introduction

This chapter reviews the general technology of remote sensing and its usefulness for applications in the field of desertification study. Remote sensing, field monitoring, observation of productivity changes and land users' opinion and modeling are other methods that can also be used in land degradation assessments (Van Lynden and Kuhlmann 2002).

Remote sensing provides a wide range of effective tools for mapping and monitoring arid and semi-arid land. Earth- observing satellites have yielded multi-spectral data such as Landsat the *MSS, TM* and *ETM* sensors and provide an ever increasing database. There are unique advantages in the application of remote sensing to the environmental assessment of desert region. Both space-borne and airborne remote sensing provides valuable tools for evaluating areas subject to desertification. Information can be obtained from direct measurements or indicators. Large-scale aerial photography provides a great amount of detail for desertification studies. Systematic reconnaissance flights can be used for environmental monitoring and resource assessment. Radar sensors and IR scanners may be used to monitor soil moisture and other desertification indicators. However, acquisition of this type of data is costly and time-consuming. The use of satellite imagery is recommended during the first stages of a detailed desertification study, since it offers an overview of the entire region. As for any other natural-hazard-related study, the data from aerial and space remote sensing must be combined with data collected on the ground. Together, these can provide the basis for the assessment.

4.2 Platform and satellite sensor

Considering the very high number of sensors that are available today and the wide range of characteristics thy have, it is proposed to regroup these remote sensing data into four categories:

1. The low and medium spatial resolution civilian optical satellites that are mainly used for monitoring purposes of the globe on a one or two-day basis. These are mainly the ones covered by the Meteosat series, the NOAA AVHRR series, the SPOT 4 and 5-vegetation instrument, and the MODIS satellite.

2. The high-spatial resolution civilian optical data that are more used to map land resources at a national or sub-national level. Among them are the Landsat series (started with MSS in the late1970s) now taken over by the Landsat TM series (lastly Landsat 7/ETM+), the SPOT series (lastly the SPOT/HRV), the Indian LISS and IRS series.

3. The very high spatial-resolution civilian optical data, whose ground resolution is in the range of a few metres, have been made available for rather detailed surveys over the last few years. Among them should be mentioned the Russian KFA 1000, the US IKONOS and Quick bird, and the French HRS/SPOT.

4. The space borne radar data with a ground resolution ranging from low to high and which are more specifically aimed at observing specific Earth features (e.g. water), in all weather and Sun illumination conditions. These include, for example, the European ERS series and the Canadian Radarsat series.

The first Shuttle Imaging Radar System (SIR-A), flown on the U.S. space shuttle Columbia in 1981, recorded images that show buried fluvial topography, faults, and intrusive bodies otherwise concealed beneath sand sheets and dunes of the Western Desert in Egypt and the Sudan. Most of these features are not visible from the ground. The radar signal penetrated loose dry sands and returned images of buried river channels not visible at the surface. These images helped find new archeological sites and sources of potable water in the desert. These "radar rivers" are the remnants of a now vanished major river system that flowed across Africa some 20 million years before the development of the Nile River system. Radar imagery is also a powerful tool for exploring for placer mineral deposits in arid lands.

In 1972, the United States launched the first of a group of unmanned satellites collectively known as Landsat. Landsat satellites carry sensors that record portions of the electromagnetic spectrum as it reflects off the Earth. Landsat acquires digital data that are converted into an image. The scarcity of vegetation makes spectral remote sensing especially effective in arid lands. The Landsat Thematic Mapper (TM) has increased our ability to detect and map the distribution of minerals in volcanic rocks and related mineral deposits in arid and semiarid lands.

4.3 Application of remote sensing to dryland degradation studies

Remote sensing is a collective name for several techniques which study at distance the ground surface or the atmosphere. Sensors installed on satellites or airplanes receive and/or send radiation to the earth. The variation in amount and wavelength of the reflected energy between studied objects or phenomena gives the object its spectral signature and makes it possible to distinguish between different types of land use, vegetation, soils etc (Hoffer, 1978).

Landsat TM and SPOT HRV data have found widespread use in agricultural land cover studies in semi-arid environments. The application involves both visual and/or computer assisted interpretation techniques, and it may be based upon single satellite images or on time series of images from different seasons or years. If the area to be studied is relatively large, satellite images will often be an inexpensive alternative to traditional sources, presuming that the ability to handle the data is already established. Results tend to be the most reliable in areas with the following properties: simple land use pattern with few crops, good spectral contrast between crops and natural vegetation, flat, good chances of cloud-free days during the growing season, relatively large and rectangular fields or clusters of fields with distinct boundaries (Rasmussen, 1993).

Regarding biomass production on pastures, it has been demonstrated that it is difficult to apply high resolution satellite images from the Landsat and SPOT series because sometimes extremely high natural within- and between-year variability tend to obscure any long-term trends in vegetation cover (Ahlcrona 1988).

Remote monitoring has long been suggested as a time- and cost-efficient method for monitoring changes to desert environments. In this capacity, it can serve both to enhance monitoring efforts as well as provide valuable information on dryland degradation in specific areas. In this section, uses of remote sensing for deriving process relevant environmental information from optical remote sensing data in deserts will be highlighted with a focus on the use of remote sensing in land degradation studies.

4.3.1 High-resolution remote sensing in deserts

Schlesinger *et al.* (1996) have noted that a principal change that occurs in degrading arid and semiarid lands is a change in the scale of heterogeneity. As semiarid lands degrade from relatively homogenous grasslands to heterogeneous shrub lands, the scale of spatial variability increases. The use of spatial statistics on soil samples in the Jornada LTER site allowed Schlesinger *et al.* (1996) to identify this change in scale. This effect is clearly seen in remote sensing images.

Okin and Gillette (2001) extended the use of spatial statistics in desert remote sensing to show their utility in determining the radial distribution of vegetation in the same landscape as Phinn *et al.* (1996). They showed that high-resolution panchromatic aerial photographs (digital orthophoto quads from the USGS with ground resolution of 1 m) could be used to confirm the presence of and determine the orientation of "streets" in mesquite (Prosopis glandulosa) dune lands. Streets are long corridors of unvegetated soil in these dune lands which may account for the much higher rates of wind erosion and dust emission observed in these landscapes.

Hudak and Wessman (1998) used both geostatistical and textural analysis of high-resolution aerial photographs to characterize woody plant encroachment in a South African savanna. Their results suggest that historical aerial photography combined with current sources of high-resolution data (either aerial photography or high resolution space instruments such as IKONOS) can be used to monitor changes in woody composition of desert landscapes.

All current and near-future spaceborne optical remote sensors fall into one of three categories: panchromatic sensors, multispectral sensors, or hyperspectral sensors. In sensor design, significant tradeoffs exist between available light energy, signal to noise ratio, temporal coverage, ground resolution, swath width, and downlink bandwidth. For example, a hyperspectral sensor with a large number of bands has little light energy available in each band which can result in low signal-to-noise or else be compensated for by a coarse spatial resolution. Alternatively, panchromatic sensors that have only one band in the visible spectrum may have very fine spatial resolution because sufficient energy exists in this portion of the spectrum, especially for sensors with a single band. Panchromatic sensors are therefore very useful in providing textural information because their pixel size may be smaller than the scale of heterogeneity on the surface while maintaining reasonable data rates. Very wide-band observation in the visible, and possibly in the short-wavelength near infrared, will allow discrimination of vegetation and soil or observation of shadows cast by ground elements. Either vegetation/soil discrimination or shadow observation on a very fine scale allows textural analysis of many types (Okin *et al*, 2001)

4.3.2 Multispectral and hyperspectral remote sensing in deserts

Hyperspectral sensors, also called imaging spectrometers, provide data in a large number of narrow, contiguous bands that cover the entire reflected solar spectrum. These sensors typically provide data in very narrow swaths (such as the New-Millennium Earth Observer 1Hyperion instrument or the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)) or with large pixel sizes (such as the Moderate Resolution Imaging Spectrometer (MODIS) instrument). Hyperspectral data cover the visible/near-infrared (VNIR) water absorption region and therefore atmospheric water vapor and apparent surface reflectance can be retrieved on a per-pixel basis using purely radioactive transfer methods (Green *et al.*, 1993).

a) Multispectral Remote Sensing

Multispectral data have been used for a wide variety of landscape ecological applications. Since rigorous reflectance retrieval is quite difficult with these data, a frequent use of multispectral data is with vegetation indices. In arid and semiarid environments, this approach is quite often not effective. Briefly, vegetation indices are likely to underestimate live biomass in deserts, are insensitive to non-photosynthetic vegetation, and are sensitive to soil colour. Spectral mixture analysis (SMA) has been widely used in studies of vegetation cover in arid regions (Elmore *et al.*, 2000).

b) Hyperspectral Remote Sensing

Multispectral data have been widely used in studies of land degradation in arid and semiarid regions. As hyperspectral data become more widely available, these data contribute to a much greater understanding of the dynamics of dryland environments and the degradation processes that threaten them. At the same time, these data are faced with the same challenges that confront all remote sensing in drylands. Early use of AVIRIS data by Elvidge *et al.* (1993) to detect vegetation at extremely low covers showed that the vegetation red edge could be detected for green vegetation cover as low as ~5%. These investigators used cultivated Monterey pine stands, which likely had more distinct red edges than are commonly found in native communities.

In an attempt to develop a hyperspectral vegetation index that would be insensitive to soil colour and would work at low vegetation cover, Chen *et al.* (1998) proposed two derivative-based vegetation indices that can be used with hyperspectral data. These indices calculate the integral of absolute value of the first or second derivative of apparent surface reflectance from approximately 626 nm to 795 nm (the range of the red edge) after the effect of local soil color has been removed.

4.4 Potential of Remote Sensing for land degradation information needs

Satellite imagery holds great promise for undertaking an inventory of environmental conditions, especially land degradation features. The promise is yet to be fulfilled but progress continues to be made as satellite sensors capable of higher and higher resolution (detail) are developed. Additionally, remotely sensed data are provided in digital form, and therefore a wide range of processing techniques are available to discriminate changes in multi-temporal data (Jensen, 1996).

In arid regions, multi-temporal analysis of indices have been applied to monitor soil degradation associated with cattle grazing (e.g. Pickup & Chewings, 1994), as well as to follow seasonal trends in vegetated dunes, discriminating the most degraded ones (Jacobberger and Hooper, 1991). This approach has made it possible to monitor temporal changes in the desert boundary of the Sahel from the NOAA meteorological satellite (e.g. Tucker *et al.*, 1991, 1994). Desertification is a dynamic process. A number of indicators of desertification are necessary in order to evaluate its effect on the land. Indicators of desertification have been grouped into Physical, biological, and social.

4.4.1 remote sensing of vegetation parameters

The hot deserts of the world are characterized by low precipitation and high potential evapotranspiration. Vegetation is therefore largely limited by the lack of water and deserts typically have low vegetation cover. This provides a near-optimal situation for geological remote sensing in arid regions because there is little vegetation to obscure the spectral signal of the geological substrate. This fact has lead to important advances in geological remote sensing in arid regions and has allowed remote sensing to make contributions to a wide variety of fields including geomorphology and economic geology (Clark, 1997).

Roberts *et al.*, (1997) summaries the retrieval of vegetation parameters from remote sensing which presents some significant challenges:

1) Low vegetation cover over bright soils means the vegetation signal can be swamped out of the pixel-averaged signal,
2) Exposed, variable soil surfaces can contribute significantly to within-scene variability,
3) Many remote sensing techniques are insensitive to non-photosynthetic vegetation (NPV), which can be a major and important component of total cover in deserts,
4) Open canopies and bright soils in desert areas can contribute to significant multiple scattering and nonlinear mixing in deserts,
5) Desert vegetation is spectrally dissimilar to its humid counterparts lacking, most notably, a strong red edge, and
6) Rapid phonological changes are accompanied by spectral changes in desert vegetation, which can lead to significant temporal and spatial intraspecies spectral variability.

4.4.1.1 Vegetation mapping

The use of vegetation indices to detect and map vegetation is widely accepted. Such indices focus on the use of red and near infrared wavebands where differential reflectance by photosynthetically active vegetation gives a low red and a high near infrared response. Indices range from a simple red/near infrared ratio to more complicated indices that include terms relating to background soil conditions and atmospheric effects. The Soil-Adjusted Vegetation Index (SAVI), a modified version of the NDVI was proposed by Huete (1988). It 'calibrates' a vegetation index, effectively normalising differences in soil substrate, thus allowing a more accurate estimate of vegetation cover.

This study used the soil-adjusted vegetation index (SAVI). Huete (1988) introduced a soil calibration factor in form of Leaf Area Index (LAI) to the NDVI equation to account for the first order soil –vegetation optical interactions and differential red and NIR extraction through the vegetation canopy. This technique is SAVI, which is a compromise between Normalized Difference Vegetation Index (NDVI) and Perpendicular Vegetation Index (PVI). It is defined as:

$SAVI = [(R_{nir} - R_r)/ (R_{nir} + R_r + L)](1 + L)$

Where,

L = a constant (LAI) introduced to minimize the influence of soil brightness

R_{nir} and R_r = reflectance of bare soil in NIR and R-band respectively

Where L varies between 0 and 1 and its weighting is dependent on vegetation cover or soil moisture conditions (Huete, 1988). The SAVI was calculated using the channels 3 (red band) and 4 (near-infrared band), according to Huete (1988) where L is a constant soil adjustment factor (L=0.5) to reduce the soil background effect. Although Huete (1988) found the optimal adjustment factor to vary with vegetation density, he used a constant (L=0.5), since this reduced soil noise considerably throughout a wide range of vegetation densities.

4.4.2 Soil types and conditions

a) Soil types

Remote sensing can provide useful information on soil types and soil conditions. As far as soil types are concerned, countries usually do have soil maps that describe in detail the soil categories, but very little is said on the status of the soil or the actual level of degradation. Land form analysis and vegetation analysis is essential to map soil types and organize the sampling of soil profiles on the ground. RS can assist in filling some gaps if necessary. Having information on soil types is important for identifying areas, which are susceptible to erosion, degradation, and soil fertility loss.

4.5 Desertification monitoring by satellites

Several geostationary and polar-orbiting satellites (e.g., METEOSAT/GOES, NOAA AVHRR, Landsat, SPOT-HRV and -VEGETATION, IKONOS) are available which operate in the reflective and emissive domain and offer a considerable potential, the various data sources available through remote sensing offer the possibility of gaining environmental data over both large areas and relatively long-time periods. Remote sensing systems, and in particular Earth observation satellites, provide significant contributions to desertification assessment and monitoring, particularly by providing methodological pathways for scaling up the results of field investigations and by supplying the spatial information needed for regional scale analysis of the relationships between climate change, land degradation and desertification processes. It seems obvious that the identification of degraded areas in the sense of environmental inventories provides the fundamental basis for better understanding the processes of land degradation and desertification in their spatial context.

A wide range of processing techniques are available to discriminate changes in multitemporal data (Jensen, 1996). These properties enable the use of satellite remote sensing for monitoring trends of land degradation as well as to identify and characterize sand dunes and their temporal dynamism in the study of desertification (Chen *et al.*, 1998). The monitoring has been mainly based on the analysis of a time series of spectral vegetation indices (VIs) VIs are arithmetic transformations of spectral bands that emphasize vegetation over soil signals (Sellers, 1989). Usually, the red and infrared reflectances are combined (Bannari *et al.*, 1995) since in the red the vegetation strongly absorbs incident radiation (up to 90%, caused by the leaf pigments) while in the infrared green leaves is highly reflective due to leaf structure. This strong reflectance contrast is only observed in green vegetation, since bare soils present a similar reflectance in both bands (Mulders, 1987).

4.6 Constraints and limitation

In general, there is a lack of awareness of the technical possibilities and limitations of satellite remote sensing technology, and its potential benefits. Remote sensing should be seen as a method for acquiring data and not as a tool to solve development problems. The proliferation of remote sensing centres may become expensive unless it is coordinated so that data gathering can be conducted with minimum overlap. In many countries the use of aerial photography is limited, or even restricted. Therefore, civilian decision makers must often use inappropriate material to generate the type of data, which would technically be readily obtainable from aerial photography. On the other hand, the civilian bureaucracy often blames its shortcomings on restriction, which may not in fact exist (Thung, 1985).

Constraints of satellite data can be divided into the following:

- ***Spatial constraints***: until the new generation of satellite instruments became available, a serious constraint was the information content in satellite data. Many of the mapping requirements could not be met. Even if satellite image were available at scales like 1:25,000, they would not contain the same amount of information as aerial photos at the same scale.

- ***Spectral constraint***: for the land cover application of satellite remote sensing, Landsat TM and SPOT HRV data are considered the most significant data used for this application. In most land applications of multispectral scanner data from satellites the number of visible and NIR spectral bands of Landsat TM six, is adequate. SPOT XS has only three bands, red, green, and blue. These three bands limit the discrimination of different reflectance features, which comprise the different land use classes. The use of remote sensing to understand land use and land degradation is a common goal in modern research. Nonetheless, special complications are presented when using remote sensing to look at soils and vegetation in deserts. These arise from the sparse vegetation cover, spectrally unique vegetation, and bright soils common to arid regions and cannot be taken for granted.

- ***Climatic constraints:*** the most important constraint for acquiring satellite data is the frequency of clouds and haze, as the instruments on Landsat and SPOT cannot see through them. This is illustrated by the fact that only around 20 percent of the images held in the global archives are estimated to be useful judging by the cloud-cover, and the probability of getting useful data is equivalently low. Areas such as Libya have guaranteed cloud-free conditions for a large part of the year.

- ***Financial constraints:*** another limiting factor for many developing countries is that foreign exchange reserves have to be used to purchase the data. One effect is that support from institution in industrialised countries is frequently needed.

4.7 Conclusions

This chapter discussed the potential of remote sensing to support the land degradation assessment in drylands implementation. Remote sensing can greatly assist in identifying areas of negative (or even positive) trends of the dynamics of land and the natural resources, which are directly related to the desertification process and can be used to stratify the territory and to optimise a field sampling design for in-depth desertification studies.

The advantages of RS imagery include capacity to analyse the landscape in a holistic manner elaborate land cover maps to perform field survey on desertification. Remote sensing can map directly many areas under some specific desertification process. It was shown that in certain cases, land cover analysis allows to identify specific features of desertification, (FAO, 2001).

Remote sensing may appear rather complex in the framework of the land degradation assessment in drylands considering the large number of parameters it is supposed to cover and in view of the rapid increase of sensors and remote sensing research programmes dealing with natural resources. However, the following conclusions can be drawn from this chapter:

- Remote sensing is of paramount importance for desertification studies, and in particular for the land degradation assessment in drylands

- Remote sensing offers a wide range of approaches and techniques, which, if well managed, can be synergetic and provide a ready added value in most methodological station basically, RS offers three main categories of information of potential use for land degradation:

RS can be used to monitor at a national/sub-regional scale:

- Vegetation activity
- Rainfall
- Human pressure on the land and agriculture intensification
- Complex ecosystems interaction

2. RS can be used to stratify the territory and to optimize a field sampling design for in-depth desertification studies. The advantages of RS imagery include capacity to:

- Analyse the landscape in a holistic manner
- Elaborate land cover maps to perform field survey on desertification

3. RS can map directly many areas under some specific desertification process.

Land cover analysis allows the identification of specific features of desertification.

CHAPTER FIVE

GIS AND MULTI-CRITERIA DECISION MAKING FOR LAND SUITABILITY ASSESSMENT

5.1 Introduction

Geographic Information Systems (GIS) have become an essential tool for spatial analysis. Historically, GIS functionalities have been limited to a set of tools for the input, storage and retrieval, manipulation, output of spatial data. Lately, these tools have been expanded beyond map-making functions into domains of problem solving and especially modeling and decision-making (Eastman, 1995).

Guptill (1989) defined a GIS as "...a system of computer hardware and software designed to allow users to collect, manage, and analyze large volumes of spatially referenced data and associated attributes." GISs evolved as a means of assembling, storing, and analyzing diverse spatial data, with the geographic location of the data serving as the basis for the information systems. "The functional components of a GIS are grouped into five categories: user interface, system/database management, database creation/data entry, data manipulation and analysis, and display and product generation" (Guptill, 1989). Two common approaches used to represent the locational component of geographic information in most GISs are raster and vector data structures (Ehlers and Greenlee 1991, Lillesand and Kiefer 1994).

Raster and vector data systems each have advantages and disadvantages (Lillesand and Kiefer 1994). Raster systems have a simple data structure, they perform such operations as overlay analysis with increased computational efficiency (Ehlers and Greenlee 1991), and they effectively represent features having high spatial variability. However, data storage, spatial resolution of data, and accurate representation of topological relationships among spatial features can be a problem with raster data systems. In contrast, vector data systems produce lower volumes of data, they have improved spatial resolution, and they maintain topological relationships making network analysis more efficient. Disadvantages of vector data systems include a more complex data structure and increased computation time for such operations as overlay analysis.

There has been much debate as to which data structure is the most effective in terms of storage efficiency, processing efficiency, and representation of spatial relationships (Ehlers and Greenlee 1991). The "...nature of the application, the kinds of data and information, and the distribution of the queries" all affect which data system is employed. Thus, there is no clear answer to this debate, as *the* most appropriate system changes with every situation. Fortunately, most GISs today support conversion between raster and vector formats, as well as the simultaneous integration of both data structures (Lillesand and Kiefer 1994). Both raster and vector data structures were used in this study, because digital remote sensing images are collected in a raster format, and vector data structures are typically employed in the digitizing and topology-producing processes (Ehlers and Greenlee 1991). In this study, a raster model has been used in producing the maps.

5.1.1 Integration of Remote Sensing and Ancillary Data within GIS

"One of the most important benefits of a GIS is the ability to spatially interrelate multiple types of information stemming from a range of sources." (Lillesand and Kiefer 1994). An important form of data merger employed in digital image processing is the registration of image data with ancillary data. Ancillary data may be choroplethic maps of various land attributes such as soil type and land cover, or maps of terrain characteristics such as slope azimuth, slope magnitude, and elevation (Hutchinson 1982). The basic logic behind data merging is that classification accuracy based on both image and ancillary data will be an improvement over a classification based on either image or ancillary data alone (Chavez 1986).

The large volume of data generated by satellites cannot be used to its fullest potential if the information cannot be accessed and analyzed in an orderly and timely fashion (Jakubauskas *et al.* 2002). "Geographical information systems (GIS) provide a means by which this information can be organized, integrated with ancillary data, and analyzed. "(Jakubauskas *et al.* 2002).

Geographic Information Systems (GIS) have become an essential tool for spatial analysis. Historically, GIS functionalities have been limited to a set of tools for the input, storage and retrieval, manipulation, output of spatial data. Lately, these tools have been expanded beyond map-making functions into domains of problem solving and especially modeling and decision-making (Eastman, 1995). These enhanced capabilities enable users to take advantage of the display capabilities of GIS and the analytical power of models. Advanced GIS capabilities including map or image computations, map algebra processing of logical expressions, and image processing make it possible to couple analytical models with GIS.

The use of GIS in this study was to generate a composite map for decision makers by using some important factors causing desertification. The study reviewed the role of GIS in decision-making and then outlined the evaluation approach for many criteria in decision processes. The design of a multicriteria environment (MCE) attempted to use a variety of evaluation techniques to obtain data from GIS and to present them in a manner familiar to decision makers. The Weighted Linear Combination (WLC) approach was used in integrating MCE with GIS.

5.1.2 Weighted linear combination (WLC) method

The weighted linear combination method is probably the most common method used for computing index values (Saaty, 1980; Banai-Kashani, 1989; Malazewski, 2000). This method used a weighting scheme to integrate criteria into a single measure (Malczewski, 1999). This method is a mathematical expression that is used to assess the suitability of one region for a particular purpose and the significance of its multiplier effect as indicated by its importance weight.

In general, the WLC method is applied by calculating the product of weight and factor with all constraints at any location, and then summing up all products, which yields an expression as follows:

$A = Wi\ Xi$, or $A = Wi\ Xi\ Cj$

If a constraint is part of the decision, X is a criterion score of factor i; W is the weight of factor i, and C is criterion score of constraint j

5.1.2.1 Estimating weights

A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility. Assigning weight of importance to evaluation criteria accounts for (1) changes in the range of variation for each evaluation criterion, and (2) the different degree of importance being attached to these ranges of variation (Kirkwood, 1997).

Some of the most common procedures include; *ranking, rating, pairwise comparison*, and *trade-off analysis*. They differ in terms of their accuracy, degree of easiness to use, understanding on the part of the decision makers, and in their theoretical foundation. In this study, a pairwise comparison method has been selected for estimating criterion weights.

5.1.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative, information. It is a methodology to systematically evaluate often conflicting qualitative criteria (Saaty, 1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by pairwise comparison of these criteria on a 9-point scale (table 5.1). In order to do this, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut, 1991).

Table5.1 Scale for pairwise comparison

Intensity	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

The goal or the objective of this research is the mapping of areas of vulnerability to desertification in the study area. The decision factors to relate attribute to suitability concerning a particular goal are the factors controlling land degradation in the study area. The primary decision factors considered in this study are land cover, geomorphic features, elevation, vegetation . Once the decision factors are identified and selected, sub-factors and even sub-sub-factors are identified to describe these criteria better. For example, the geomorphologic factor was sub-divided into four sub-factors. Similarly, other decision factors, like land cover and elevation, are sub-divided into sub-factors. The Relative Importance Weights (RIWs) are the normalized eigen vectors corresponding to the maximum eigen values of the pair-wise comparison matrices constructed at each level of the decision hierarchy. The RIW assigned to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. Eigen vectors were then estimated by multiplying all the elements in a row and taking the nth root of the product, where n is the number of row elements (Saaty, 1980). Normalization of the eigen vectors was accomplished by dividing each eigen vector element by the decision factor.

5.1.4 the decision making process

In this study a scientific model facilitates decision-making in order to determine the resource allocation related to activities planning. Decision-making is a sequential process (based on Malczewski, 1999):

Defining the decision problem (objective)

Determining the set of evaluation criteria to be used

Weighting the criteria

Generating alternatives

Applying decision rules

Recommending the best solution to the problem.

Any decision-making process begins with the definition of the problem or the objective to be reached. Once the decision problem is defined, what follows is setting up a set of criteria that reflect all concerns of the problem and finding measures as to which the degree is achieved. The purpose of weights is to express the importance or preference of each criterion relative to other criteria. Alternatives are often determined by constraints, which limit the decision space of feasible alternatives. Decision rules integrate criteria, weights and preferences to generate an overall assessment of the alternatives. Recommendations are based on a ranking of the alternatives, with reference to possible uncertainties or sensitivities. Sensitivities are changes in the input of the analysis that bias the outcome.

In spatial decision-making, map overlay is one of the basic data analysis methods and used to integrate data. In an overlay process, data layers are superimposed in order to produce a new data layer (Jansen and Rievelt, 1990). However, this technique has some limitations. Firstly, this technique has problems when dealing with a decision-making process of a less well-defined nature. Secondly, it has difficulties to comprehend and move more than four factors involved, especially when the variables may not be equally important. Thirdly, the technique finds difficulty when dealing with threshold values, creating problems in the polygon overlay outcome (Jansen and Rievelt, 1990).

Due to the limitations previously explained, there is a need to look at alternative techniques and methods with the ability to address those problems and to reflect a well-defined nature. The Multi Criteria Evaluation (MCE) method appears to be the answer. The following is an explanation of MCE in relation with Geographical Information Systems.

5.1.5 Multicriteria Evaluation (MCE)

In order to define the suitability of an area for a specific practice, several criteria need to be evaluated. The methodology applied here integrates a Multi-criteria Evaluation (MCE) method within the Geographic Information Systems (GIS) environment. MCE has been developed to improve spatial decision-making when a set of alternatives needs to be evaluated on the basis of conflicting and incommensurate criteria (Malczewski, 1999).

MCE is an effective decision making tool for complex issues that uses both qualitative and quantitative information.

MCE has been utilised around the world for Land Suitability Modelling and is concerned with how to combine the information from several criteria to form a single composite index of evaluation. A criterion may be a *factor* providing suitability of a phenomenon of *continuous* measure or may be a *constraint* to limit the alternatives under consideration (Eastman, 1999).

Multiple criteria typically have varying importance. To illustrate this, each criterion can be assigned a specific weight that reflects its importance relative to other criteria under consideration. The weight value is not only dependent on the importance of any criterion, it is also dependent on the possible range of the criterion values. A criterion with variability will contribute more to the outcome of the alternative and should consequently be regarded as more important than criteria with no or little changes in their range. There are several methods for deriving weights, among them (Malczewski, 1999): Ranking, Rating, Pairwise Comparison and Trade-off. The simplest way is straight ranking (in order of preference: 1 = most important, 2 = second most important, etc.). Then the ranking is converted into numerical weights on a scale from 0 to 1, so that they sum up to 1. In this study weights were calculated based on the pairwise comparison method, developed by Saaty (1980). A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9 (See table 5.1). Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons.

5.1.6 Conclusion

This chapter has discussed the principles and theories behind planning decision support systems. The theories and methods described have been implemented in this present study. One important conclusion from the above-mentioned models is that they all help in analyzing the existing land suitability methods. Most of them help, in different and limited ways, in predicting land degradation.

Methods based on traditional concepts require accurate, sophisticated and timely availability of data, both spatial and attribute, on a variety of subjects. The level of detail required for information on many functions changes frequently and is difficult to update on a regular basis, more so in developing countries. With the capability of providing synoptic views over large areas, remotely sensed data can be a useful base for carrying out macro-analyses of land degradation, at frequent intervals. It not only provides information more efficiently than field survey, it also offers a new perception and a new understanding for monitoring desertification.

CHAPTER SIX

LANDSAT TM IMAGERY AS SOURCE OF INFORMATION FOR ASSESSMENT AND MONITORING OF DESERTIFICATION

6.1 Introduction

Remote sensing is a powerful tool for the regional mapping of natural resources. With the use of imageries during the early stages of development of remote sensing in the mid-seventies, adequate progress has been achieved in the data interpretation. Digital processing of remotely sensed data has gained momentum in the last ten to fifteen years, especially with the availability of digital data. In Libya, with the establishment of remote sensing centres, attention is focussed on large-scale data processing for natural resource evaluation. One important aspect in remote sensing is the categorisation and classification of spectral measurements taken from satellite sensors into various features on land surface. Recognition of patterns for classification can be carried out if appropriate procedures are adopted. General classification methods have been developed using the image statistics, and their applicability to the processing of data is limited due to the spatial variation of natural resources.

This chapter focuses on the utilization of satellite data in providing the primary source of information for land cover mapping (maps) and monitoring of land cover changes which is discusses in more detail in the next chapter. In this study, after considering the characteristic needs for creating land cover maps with acceptable accuracy, supervised classification (maximum likelihood classification enhanced) was selected. The method is up to standard and the results met the purpose of the study. There are many methods available such as Classification by Progressive Generalisation (CPG), Expert System, Neural Network, Fuzzy Classification and etc., most are them are more complicated and specially designed for particular situations.

6.2 METHODOLOGY

Remote sensing techniques have the ability to represent land covers categories by means of classification processes. With the availability of multi-spectral remotely sensed data in digital form and the developments in digital processing, remote sensing offers a new perspective for land-cover/land-use analysis. Satellite remote sensing, in conjunction with geographic information systems, has been widely applied and been recognized as a powerful and effective tool in analysing land cover/use categories (Weng, 2001).

In this chapter, four Landsat TM5 satellite images were analysed using image-processing software (ER Mapper, version 6.3) and image enhancement techniques were applied to improve visual interpretation and mapping land cover and their changes in the study area. Figure (6.1) shows the procedures carried out for derivation of land cover information from remotely sensed data.

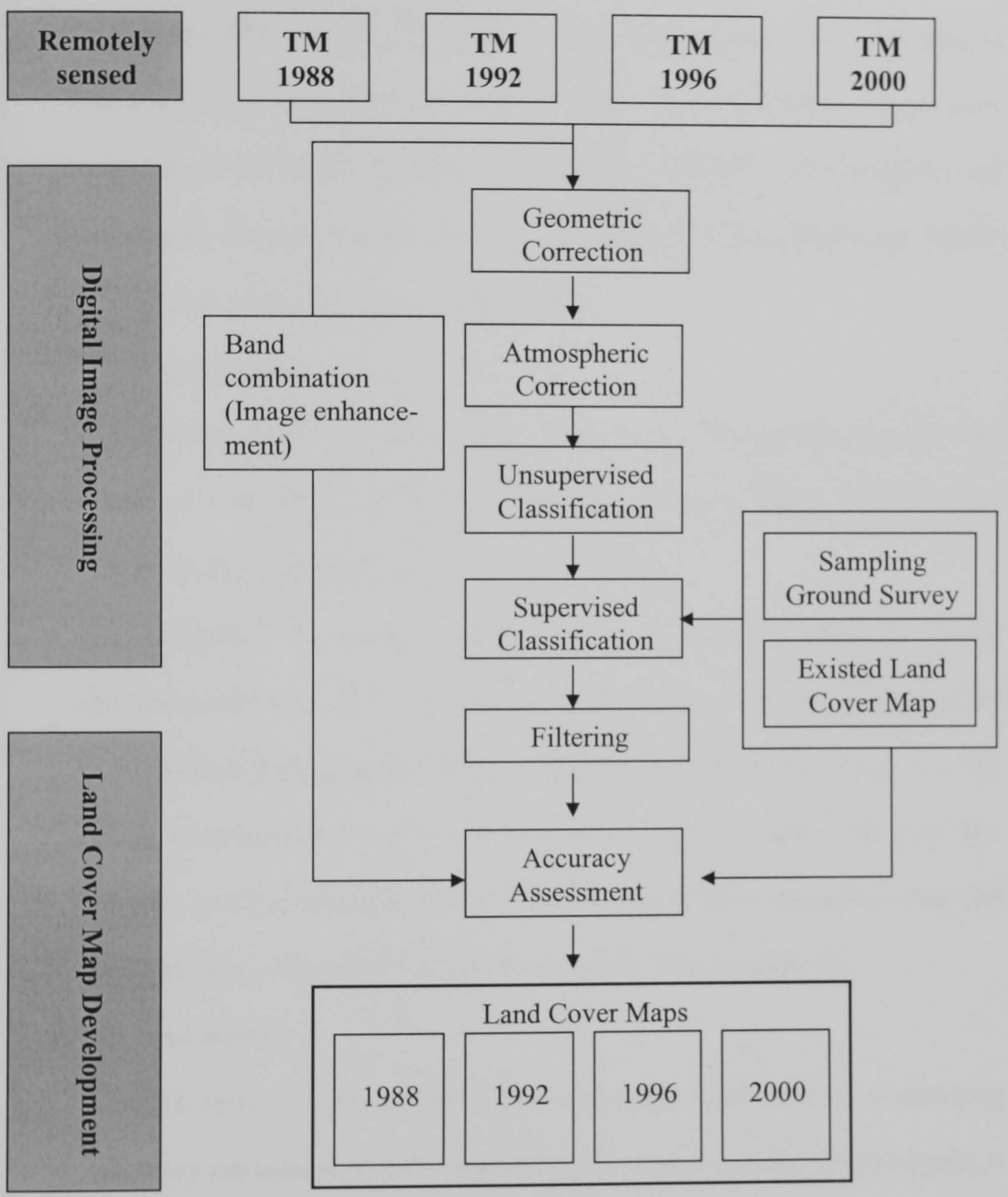


Figure 6.1: shows the procedures carried out for derivation of land cover information from remotely sensed data

6.2.1 Data input (acquisition)

a) Satellite Imagery

Four Landsat TM images; 15th August 1988, 20th August 1992, 25th August 1996, and 26th August 2000, were used in this study. All satellite images were obtained from the Biruni Remote Sensing Centre (BRSC), radiometrically and geometrically corrected (level-1G), has free of cloud cover. The scene 189/37 (path/row) has spatial resolution of 30 metres.

b) Topography Map

A digital topography map was obtained from Survey Department of Libya with a scale of 1:50,000. It was projected under the geodetic datum "WGS84" and map projection (NUTM 33) and the unit is in metres.

The total area for this study is approximately 166491ha. To ensure that all the area was covered, six digital topographic maps were used. All these maps had to be joined accurately and some feature editing needed to be done. Mosaicing and editing processes were carried out using ER Mapper 6.3. After the map was compiled and free from any error, it was saved as a base topographic map and the information were extract for several purposes (See appendix B).

c) Ground Survey

Ground survey is an important factor that has been used in determining accuracy assessment. Besides confirming the accuracy of the classified map, it also provides a better understanding of the spectral signature of various types of land use and land cover in the study area. Therefore, the information from this survey was also used to specify training areas in the supervised classification analysis.

The ground survey was undertaken to create real up to date reference land cover information. In this study, it was done by verifying the information obtained from unsupervised classification and adding new information from several sources such as images from Landsat TM (band 5,4,1), the topographic map, high-resolution data IRS PAN, SPOT 4 and SPOT 5 (see appendix C1) as well as from personal interviews of local people, and a global positioning system (GPS). All major references for the training areas were successfully assessed. Assessment was repeatedly done in several ground survey expeditions to confirm the identification of each of the land cover classes.

On each visit, the ground survey points were marked and all related information for creating land cover information was extracted (See appendix C2). To specify the points and determine the location of the area, satellite images were overlaid together with layers of road (from the topographic map). Most of the reference points of the land cover classes were selected depending on stable features such as road intersections and buildings, which are related to land cover classes (Landsat TM year 2000). Every training area that was selected must have at least one checking point to ensure the type of land cover of the surrounding area. Photos have also been taken for each visit for reference and for class determination. A total of 50 points were successfully selected and visited during the ground survey (Figure 6.2, 6.3 and 6.4).

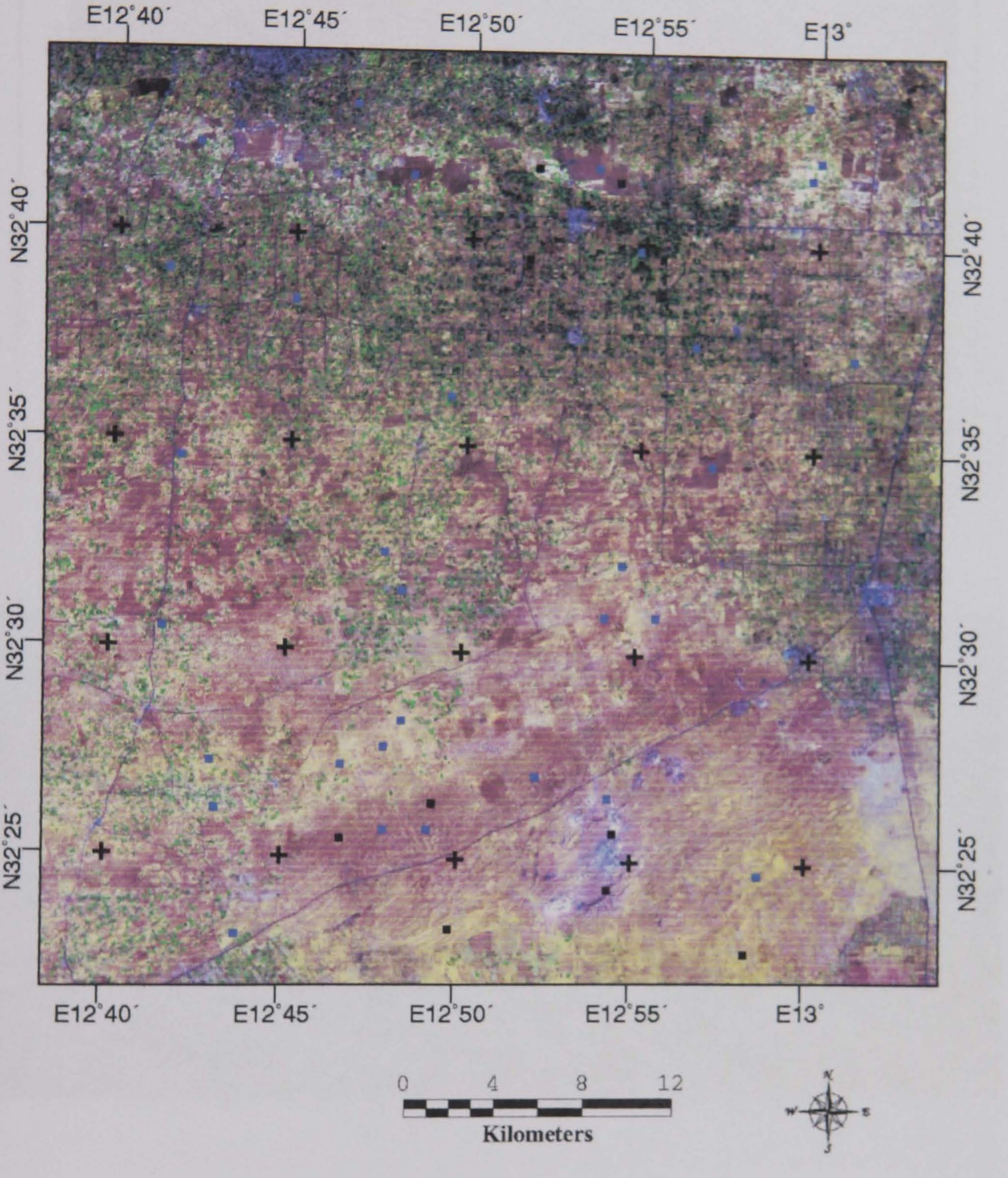


Figure 6.2: Ground checking points and Training Area of classes for supervised classification analysis.

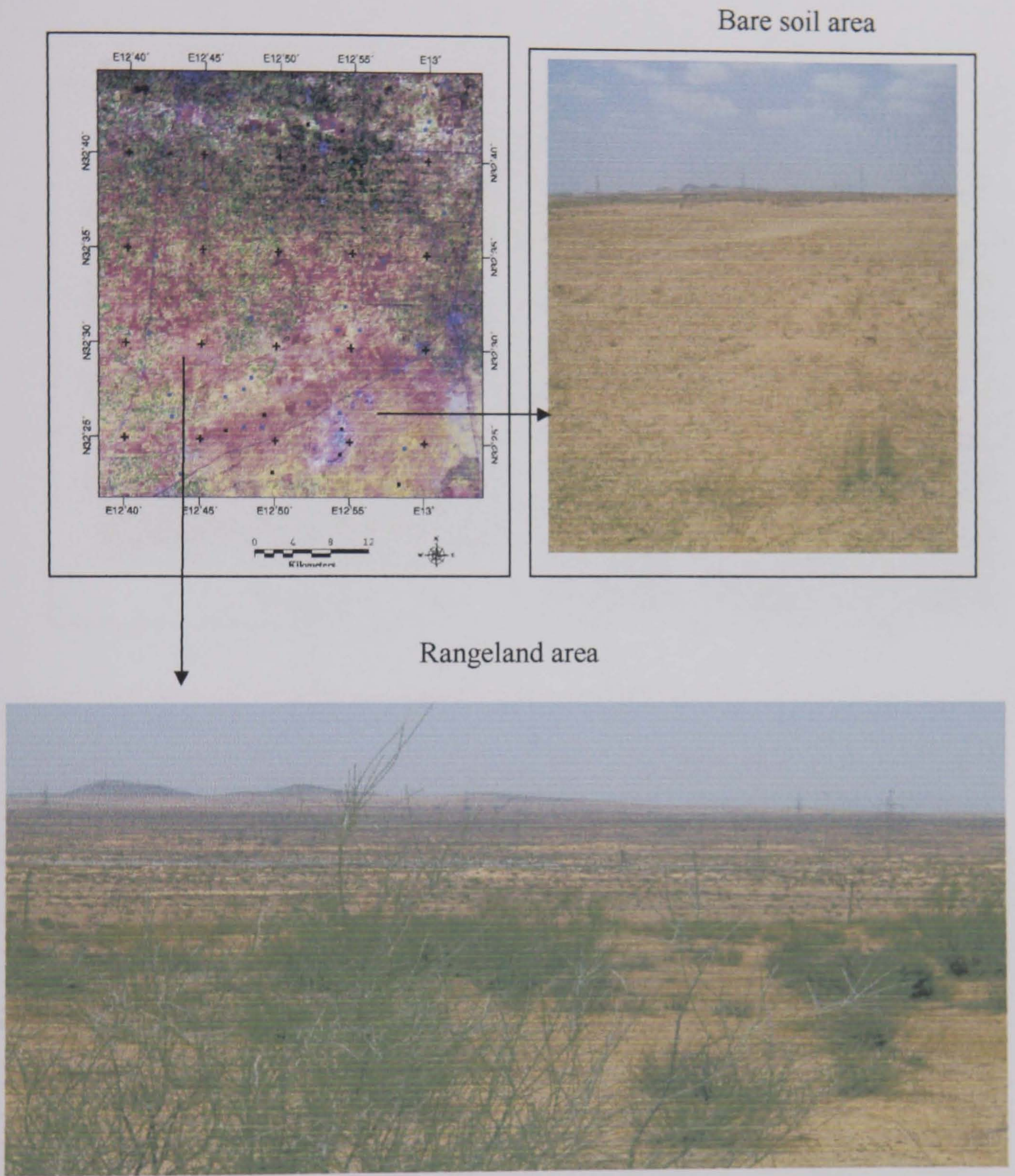


Figure 6.3 Photographs of land cover classes

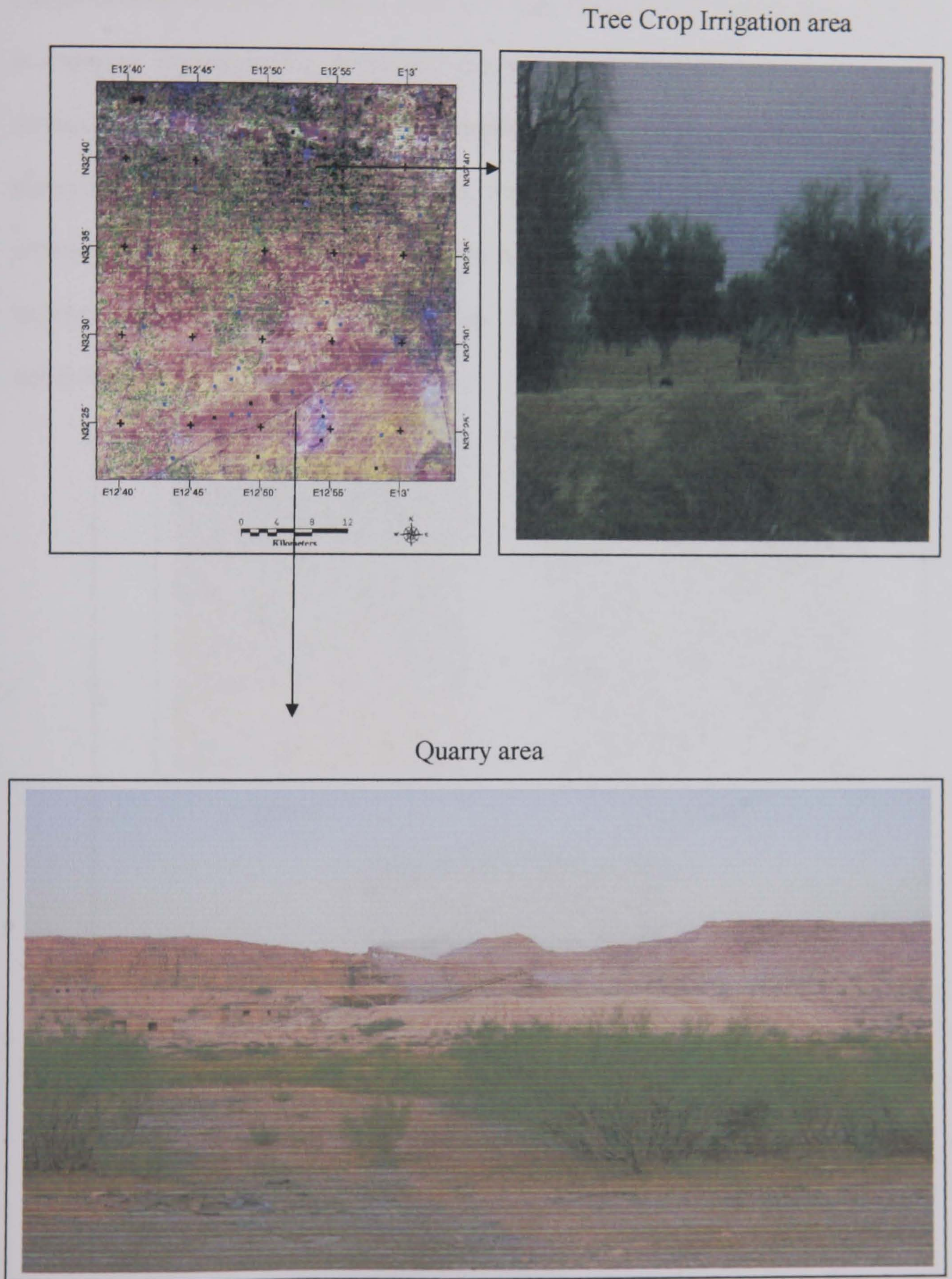


Figure 6.4: Photographs of land cover classes

6.2.2 Image processing of data

Pre-processing of satellite images prior to image classification and change detection is essential. Pre-processing commonly comprises a series of sequential operations, including atmospheric correction or normalization, image registration, geometric correction, and masking (e.g., for clouds, water, irrelevant features). Three types of contrast stretching have been used, linear, equalisation and gaussian, figure 6.5, to improve visual interpretation as well as atmospheric correction and geometric correction.

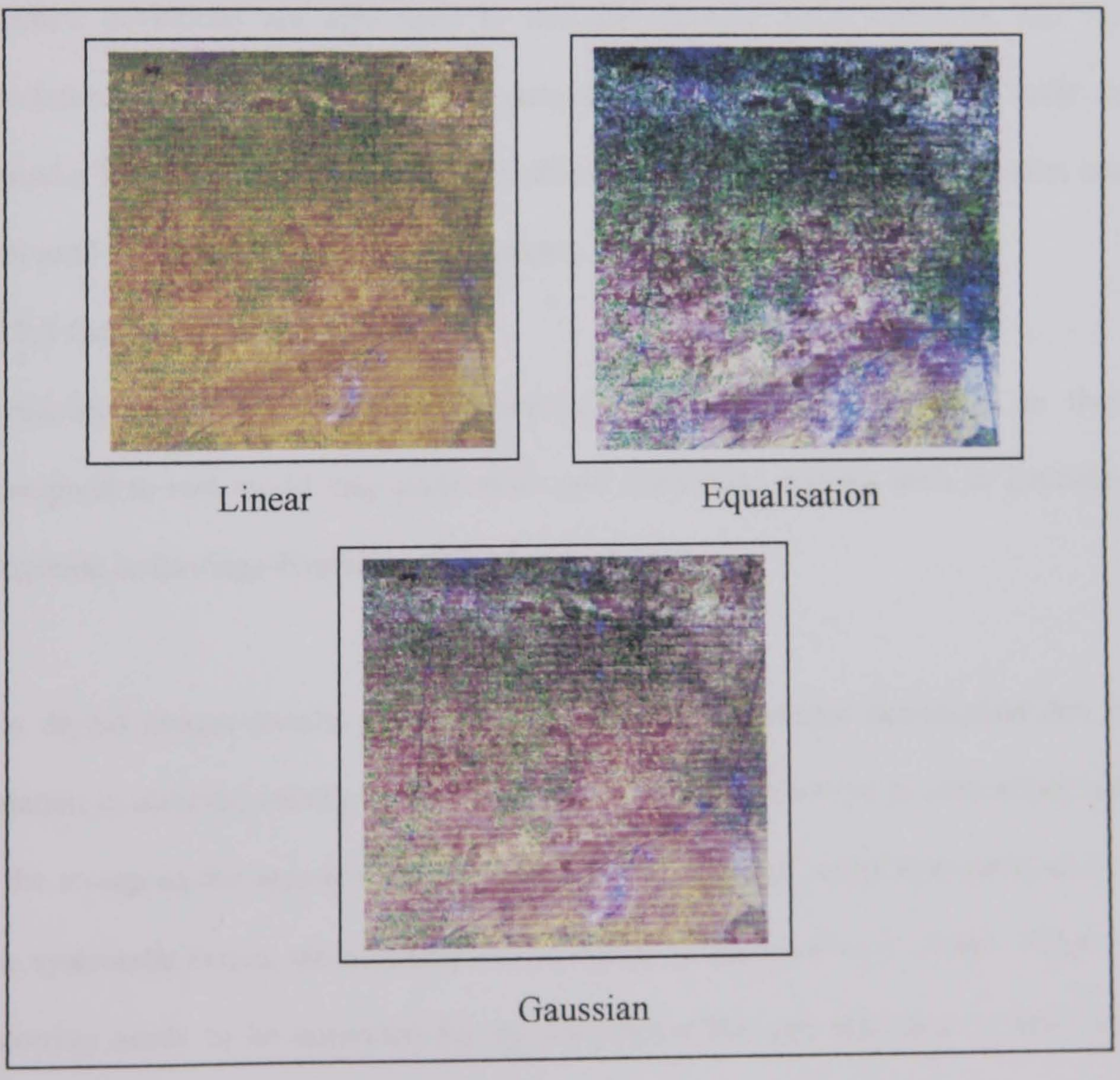


Figure 6.5. Histograms images enhancement

6.2.2.1 Selection of bands used

The selection of the bands used as false colour composite RGB from TM bands 1, 2, 3, 4, 5 and 7 except band 6 as thermal band was based on the optimum index factor (OIF) developed by Chavez *et al.* (1984) was used to evaluate the best TM band combinations. They used OIF to rank the band combinations that contained the most information and the least amount of duplication. In this study band combinations have been used and analysed for each False Colour Composite (FCC). Using OIF, based on between-band variances and correlations between bands, produced twenty images. Standard deviations are also used to indicate between band variances, and the correlation coefficients that indicate data redundancy. The results (see table in appendix E) show TM bands 541 are highest in OIF ranking. This combination has been used to assist in interpreting the images.

6.2.2.2 Geometric rectification

Rectification is the process of geometrically correcting raster images so they correspond to real world map projections and coordinate systems such as Latitude-Longitude or Eastings-Northings (ER Mapper, 2002)

Raw digital images usually need to be corrected for geometric deformation due to variation in altitude, velocity of the sensor platform, for variations in scan speed and in the sweep of the sensor's field of view, earth curvature, relief displacement etc. The systematic errors are normally corrected for at the receiving station. Random distortion needs to be corrected for by the analyst through selection of sufficient number of ground control points (GCPs) with correct coordinates, usually from a map or GPS (Global Positioning System) which can be localized in the satellite image. A transformation function is calculated to determine the distorted image positions corresponding to the correct map positions: an undisturbed output grid is defined. In a chosen resampling scheme each cell in this new grid is assigned a gray level according to the corresponding pixel in the original image (Sara and Sylvia 1998).

In this study thirty ground control points (GCPs) have been selected from the topographic map to correct the Landsat TM imagery resampling, using the Nearest Neighbour method, produced a Root Mean Square error (RMS) of less than 1.0 pixel for each scene

The geocoding process was done using the Geometric Correction Package from ER Mapper involving a regression analysis between the uncorrected image and the master data (topographic map). There are two way of doing this;

- Image with input coordinate – coordinates for each points that had been selected are input by user,
- Image to image – coordinates for each point that had been selected are automatically referred to the goecoded image.

For this study, both methods were used. Firstly, *Image with input coordinate* was used to correct the image of year 2000. Secondly, using the *Image to image* method, all others images were corrected using the geocoded image of 2000 as the main reference. This technique was used to increase the spatial accuracy between images. Figure 6.6 shows one of the GCPs used in the geometric correction process and the "geolink screen technique" was been used to compare and verify the overlay. (See Figure 6.7 and Appendix A)

Figure 6.6. White cross on road intersection is shown as one of the GCPs used in the Geometric Correction Process.

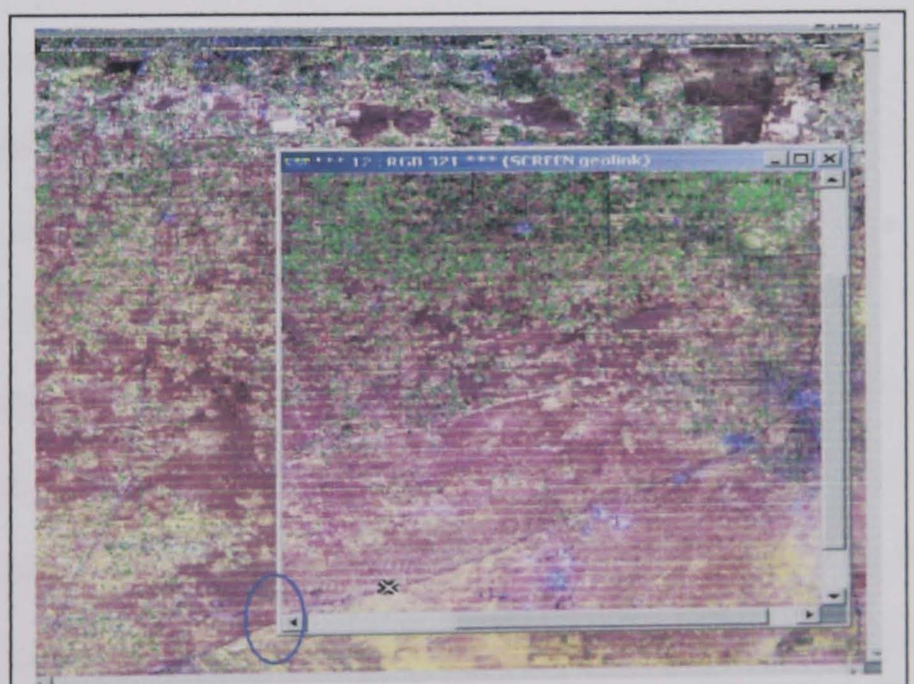


Figure 6.7. Visual verification after the Geometric Correction Process (Image overlay) using the "Geolink screen technique"

6.2.2.3 Atmospheric correction

In most cases, the atmosphere is perceived as a hostile entity whose adverse impacts must be neutralized or eliminated before remotely sensed data can be properly analyzed (Schott, 1997). It is necessary to normalize the imagery with respect to radiometric parameters when comparing between data acquired at different times (Hakan 1994). The remotely sensed image data are usually not ready for use directly, but need to go through a series of pre-processing steps in which atmospheric correction is often a primary concern. In this study, the correction of the TM dataset has used the darkest pixel improvement method which is the simplest absolute approach (Chavez, 1988; Chavez, 1989), where the minimum value of the image is subtracted from all the pixels; it is considered to be due to the atmospheric effect

6.2.2.4 Classification

The purpose of image classification is to group together pixels that have similar patterns of brightness values across a series of image bands or information channels. There are two general approaches that have been used:

6.2.2.4.1 Unsupervised classification

In unsupervised classification, a statistical technique called k-means cluster analysis is used. In this procedure, the analyst specifies the number of classes required. Pixels are initially assigned to classes at random. Once all pixels have been assigned to a class, group means are calculated for each class. Each pixel is compared to each class and is reassigned to the class with which it has the highest similarity. Once all pixels have been reassigned, class means are recalculated and the process iterates until no further changes in class membership occur. The output is a new image in which each pixel is represented by its class identifier. Unsupervised classification is useful for exploring what cover types can be detected using the available imagery. However, the analyst has no control over the nature of the classes. The final classes will be relatively homogeneous but may not correspond to any useful land cover classes. In this study, the process, unsupervised clustering is performed using the K-Means (Minimum Distance) method, a popular classifier in ER Mapper 6.3. It is performed in order to examine the data and to divide them into classes based on natural groupings of the original satellite data. A maximum of 6 classes and 6 iteration with 0.01 minimum threshold were chosen in this process. Bands 1, 2, 3, 4, 5 and 7 of the satellite image data were used in the process. The map created through this process gives basic information of classes which exist on the ground and has been used in ground survey and for creating training areas for supervised classification.

6.2.2.4.2 Supervised Classification

Supervised classification requires the user to identify the cover types of interest. Samples of pixels are then selected based on available ground truth information to represent each cover type. These samples are called training areas. The brightness values in the input image bands are analysed to generate a spectral signature for each cover type. All pixels in the image are then compared to the spectral signatures of each cover and assigned to the cover class with which the pixel has the highest degree of similarity. Nearest neighbour, parallelpiped, and maximum likelihood classifiers can be used, although the maximum likelihood method is generally preferred

A simplified procedure for performing a supervised classification is as follows:

Select training regions	Defining training regions in image (areas of known feature types or cover classes
Calculate region statistics	Calculate statistics for pixels in each training region (minimum, maximum, mean values, standard deviation, etc)
Evaluate class signatures	View and evaluate statistics for training regions in tabular format or graphical format histograms or scattergrams
Classify the image	Select a classification type (decision rule), and perform the classification to assign each pixel to one of the feature classes
Display and evaluate classification	Display the output classification image, assign colours to classes and overlay classes or use statistical means to assess accuracy

In this study, the process begins with the selection of training areas that are representative and homogenous as examples of each information category used in the classification stage. The training areas for the classes are selected after careful examination of an unsupervised classification map, topographic maps, and information collected on site. In addition, these training areas are chosen through visual interpretation of the Landsat TM R,G,B (5,4,1) and locating them in areas, which represented the land cover classes with the total range of spectral variation (Figure 6.4). Landsat TM bands 5, 4, 1 did show a high potential in expressing spectral differences base on the Optimum Index Factor (OIF). Colours technique was used to differentiate and enhance among classes by changing the colour to more contrasting combinations. A total of 6 classes were determined from Landsat TM 1988 to 2000.

In this study, maximum likelihood classification was used in the image analysis. Maximum likelihood calculations determine both the variances and correlation of the spectral response patterns for different classes, with the assumption that the distributions of the pixels forming the class training data follow Gaussian (or Normal) distributions. It usually leads to higher accuracy compared to the other algorithms. Input bands of this classification were bands 1, 2, 3, 4, 5 and 7.

6.2.3 Land Cover Map Development

a) Filtering

Isolated pixel classification errors were observed after the classification. To remove these errors, a 3-by-3-majority filter was applied to the classification outputs. In majority filtering, an n-by-n window is centred about each pixel in a given image. The value that occurs the maximum number of times among the values lying within the window is determined. This output is placed at the location of the center pixel, that is, the pixel about which the window was centred. This procedure is then repeated for every pixel in the image. Majority filtering significantly improves the classification accuracy. This filter has been used to "clean up" visually noisy classifications

b) Classification Accuracy Assessment

A Stratified Random Sampling technique was applied in order to produce the accuracy of the land cover map. Many remote sensing analysts prefer this method (Jensen, 2005), in which a minimum number of samples are selected from each class after the thematic map has been prepared. Stratified random sampling involves two steps. First, the study area is classified into land cover classes on what is found in the remote sensing classification. Some analysts prefer to mask out all unwanted classes and select only wanted land cover classes. Sample locations are then randomly distributed throughout the land cover map. Points were randomly created using the Accuracy Assessment Package in ER Mapper to all classified maps, only *selected* confidence points were used in the statistic accuracy analysis (Kappa Analysis). These points have been indicated by applying two rules:

- Selected classes – only points for selected classes were chosen,
- Confidence point – the point should belong clearly to one class.

In the assessment of the accuracy, to produce the report for the land cover map, it needs to be compared with a land cover base map that was considered accurate. These maps, produced by Agriculture Department of Libya, have been used as base maps for land cover in 1988, 1992 and 1996 and 2000 (scale 1:50,000)

When the images had been classified, ground survey was done to ensure that the classes, which were mapped effectively, corresponded to the thematic classes they were supposed to be. Estimation of this mapping accuracy was made through a confusion matrix, which provided for each class the respective proportions of omitted, committed and well-classified pixels. In this test, categorized pixels, excluding the training areas, were compared with the same sites in the field. If there were no errors recorded, the entire all the off diagonal elements would be zero. In practice there were errors of omission and commission, which indicated miss-classification. If these errors exceed an agreed percentage then the re-classification technique has to be revised.

To produce accuracy statistic of land cover maps in this study, Error Matrices Analysis and Kappa Analysis (K_{hat}) were applied to define overall accuracy and a K_{hat} value. Short explanations of these methods are shown below:

The most common and typical method used by researchers to assess classification accuracy is with the use of an error matrix (sometimes called a confusion matrix or contingency table) (Congalton, 1991). An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units (i.e., pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as confirmed on the ground. The rows in the matrix represent the remote sensing derived land use map (i.e., Landsat data), while the columns represent the reference data (i.e., aerial photo) (Jensen, 1996). The error matrix was applied to produce overall accuracy for the land cover map created in this study. The overall accuracy of the classification map is determined by dividing the total number of correct pixels (sum of the major diagonal) by the number of pixels in the error matrix (N).

These tables produce many statistical measures of thematic accuracy including overall classification accuracy (the sum of the diagonal elements divided by the total number), KAPPA analysis yields a K_{hat} statistic (an estimate of KAPPA) that is a measure of agreement or accuracy between the remote sensing-derived classification map. The K_{hat} statistic is computed as below:

$$K_{hat} = \frac{N\sum^{rows} x_{ii} - \sum^{rows} x_{class}\, x_{ref}}{N^2 - \sum^{rows} x_{class}\, x_{ref}}$$

Where, N = is the total number of observations

X_{ii} = are the observations along the diagonal

X_{class}=are the observations for classified data

X_{ref} = are the observations for reference data

K_{hat} values > 0.80 (i.e., > 80%) represent strong agreement or accuracy between the classification map and in (The ground reference information), values between 0.40 and 0.80 (i.e., 40% to 80%) represent moderate agreement and K_{hat} values < 0.40 (i.e., < 40%) represent poor agreement (Landis and Koch, 1977). Results of accuracy assessment for the Land Cover Map of 1988, 1992, 1996, and 2000 from digital image processing are shown in section 6.3.

6.3 RESULT

6.3.1 Accuracy Assessment for Land Cover Map

To test the accuracy of the computer-classified maps in every approach, the error matrix technique (confusion matrix) was used. The confusion matrix is the simplest descriptive statistic used to compare a classification result with ground truth information. "...This accuracy measure indicates the probability of a reference pixel being correctly classified and is really a measure of omission error..." Congalton (1991).

Accuracy assessment was applied to all land cover maps produced from satellite imagery. After using the methodology mentions in section 6.2 the accuracy result for each land cover map was successfully obtained and summarized in Table 6.1.

Table 6.1. Results of classification accuracies

Land cover class	Overall Accuracy	95% Confidence Interval	Kappa coefficient
1988	88.356%	82.653 % - 91.697	0.749
1992	82.373%	75.615 % - 88.153	0.643
1996	84.934%	77.659 % - 86.853	0.689
2000	89.880%	83.235 % - 90.433	0.795

Overall accuracy for each land cover map is comparatively high with all of them indicating more than 80%. The highest accuracy map was 89.880%, for year 2000 and the lowest was 82.373% for 1992. The range for 95% confidence interval is from 77.659 % to 91.697 % for all land cover maps produced in this study. K_{hat} statistic for all maps given values from 0.643 to 0.795, meaning moderate agreement between all land cover maps produced in this study compared with ground survey data. The lowest and the highest value are still for on year 1992 and 2000.

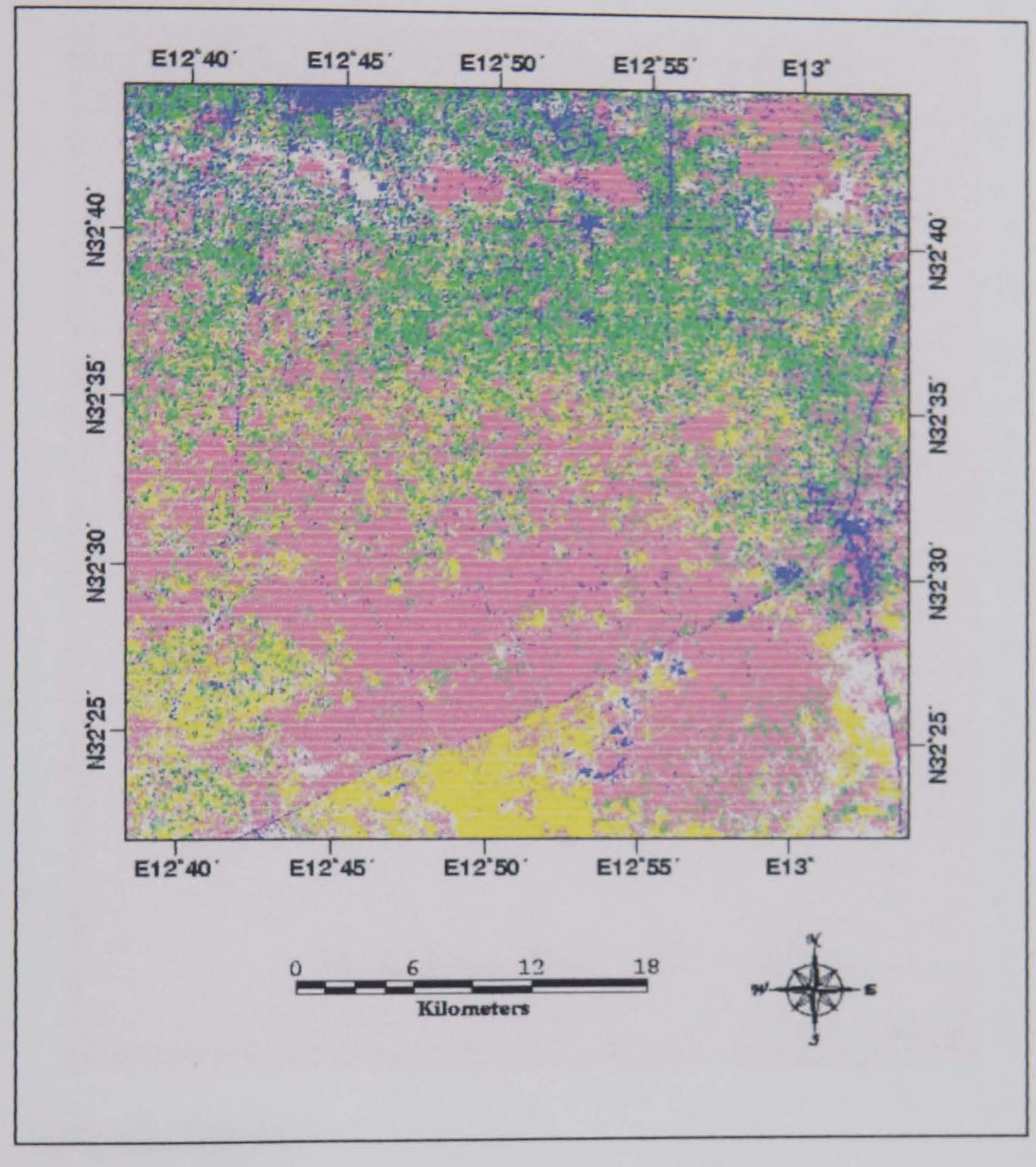
6.3.2 Land cover map

Digital image processing techniques have been used to produce the land cover map. There are five classes of land cover types, which were successfully clustered from four Landsat TM images from 1988 to 2000. The number of classes that were created depends on the complexity of spectral reflectance; at the same time indicating the number of classes that occur in the image.

Rangeland class is the largest individual class which covered approximately 42.04% – 60.37% of the study area, follow by irrigated tree crops 15.06% - 29.96%. Urban is the smallest class, which covered only 1.8% – 4.14 % of the study area. The results of image classification and land cover classes for each particular year used in this study is shown in Table 6.2 also Figure 6.8 to 6.11.

Classes	1988		1992		1996		2000	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Quarry	27325.3	7.726028	8034.750	4.814309	8168.310	4.894336	169.560	0.257446
Range Land	70166.9	42.04214	80250.210	48.08479	77592.150	46.49212	97864.740	60.37405
Bare Soil	13829.9	16.37647	28115.370	16.84633	28341.990	16.98212	25995.780	20.15954
Irrigated Tree Crops	53881.6	29.96724	47485.710	28.45277	48474.090	29.04499	41053.230	15.06233
Urban	1689.57	3.888117	3007.080	1.8018	4316.580	2.586434	6920.460	4.146642

Table 6.2. Summary of Landsat classification area statistics for 1988, 1992, 1996 and 2000



Classification key

Irrigated Tree crops

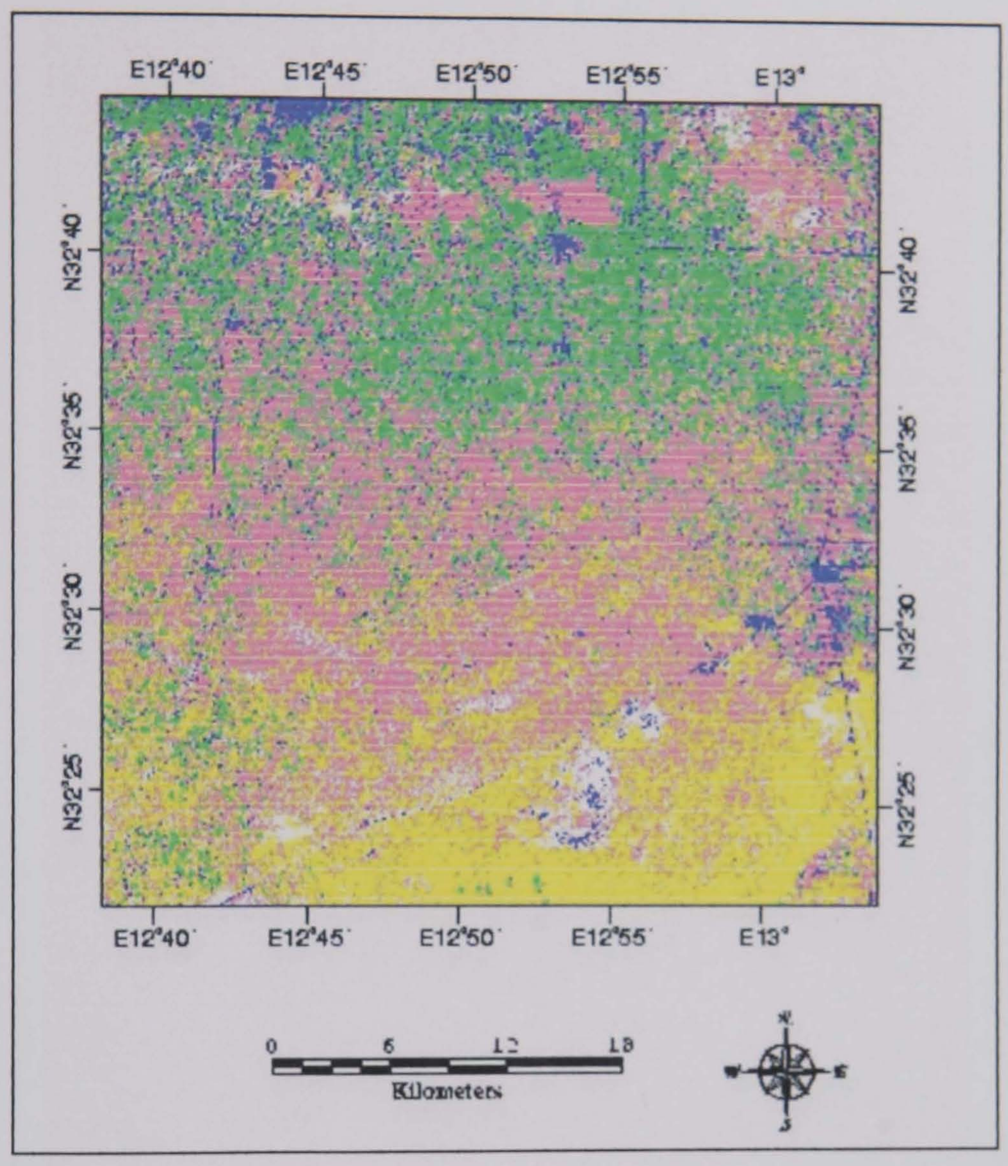
Range Land

Bare Soil

Urban

Quarry

Figure 6.8. Land cover map of 1988 of the study area



Classification key

Irrigated Tree crops

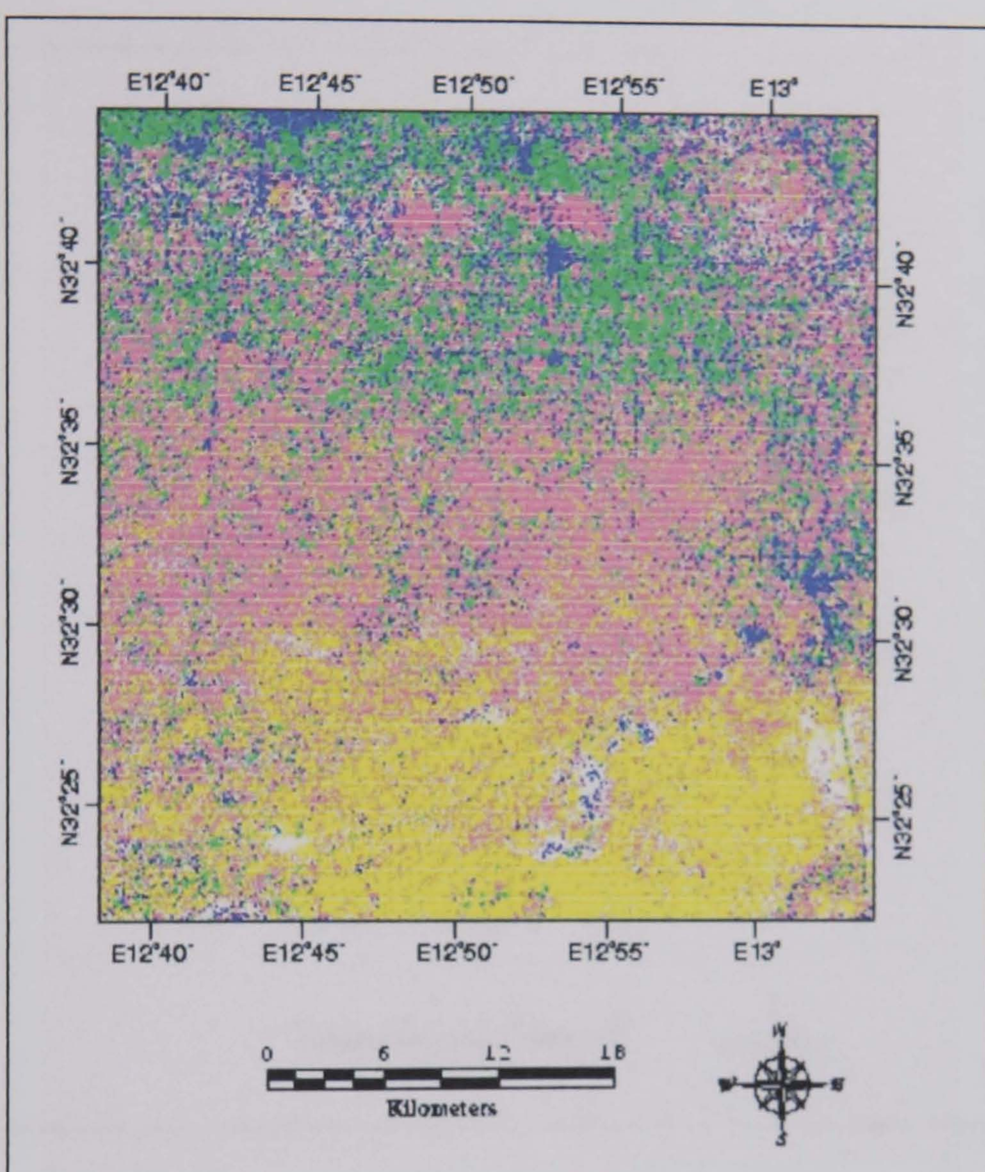
Range Land

Bare Soil

Urban

Quarry

Figure 6.9. Land cover map of 1992 of the study area



Classification key

Irrigated Tree crops

Range Land

Bare Soil

Urban

Quarry

Figure 6.10. Land cover map of 1996 of the study area

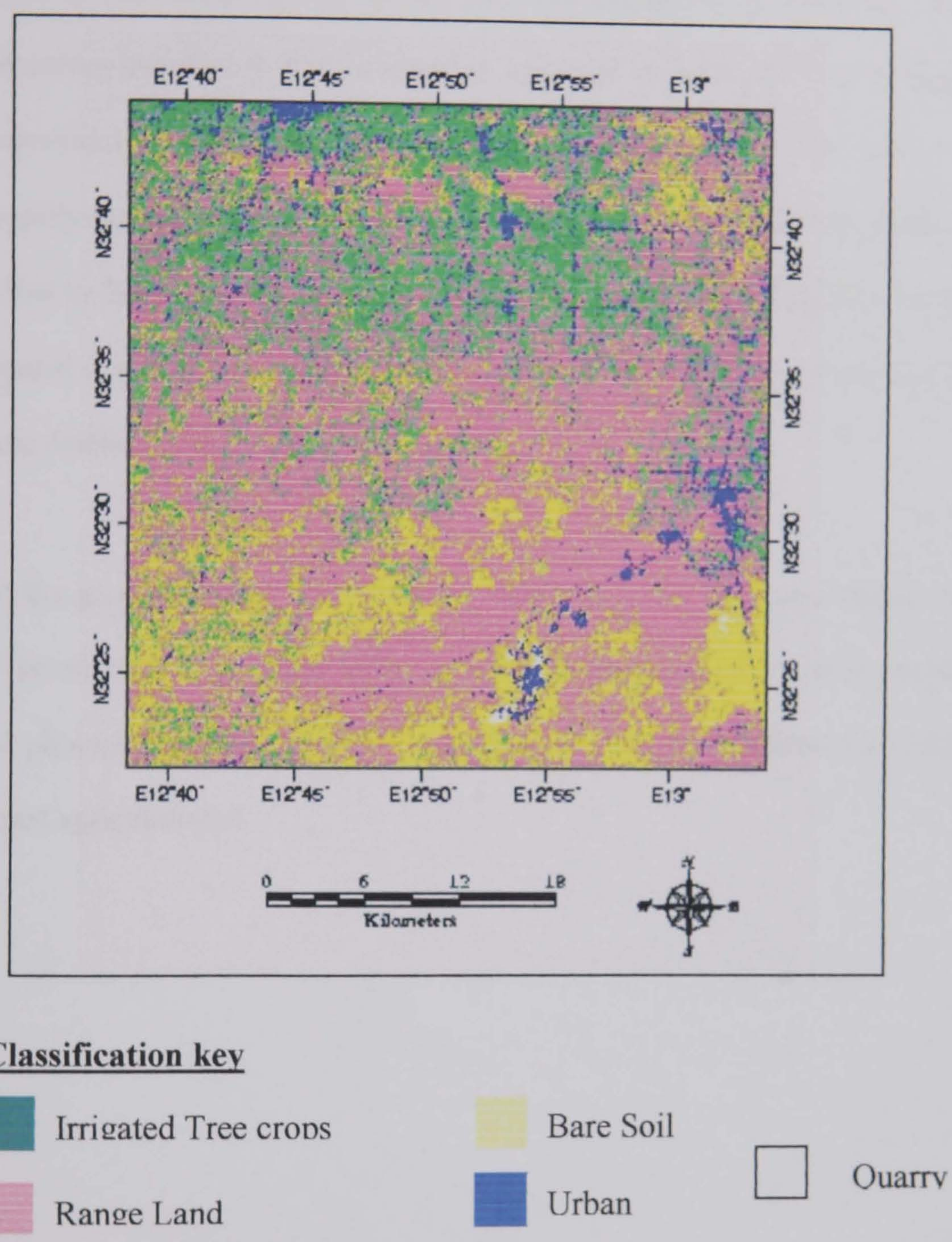


Figure 6.11. Land cover map of 2000 of the study area

6.3.3 Land Cover Activity

Detection of land cover activity in the land cover map was carried out during the ground survey expedition. The information was used to define the best training areas for supervised classification analysis. Five types of land cover classes were successfully created through digital image processing of Landsat (TM) images from year 1988 to 2000. The Land cover classes defined from ground field survey classes represented *a Range Land area, Bare Soil, Tree Crop Irrigated, Urban and Quarry* for more details see table 6.3.

During the ground survey, the activity for each land cover class was defined through visual interpretation, or questioning of an authorised person or local people, and several photographs were taken for each class for further consultancy advised from the expert agriculturalist.

Table 6.3: List of Land cover classes defined from ground field survey.

No.	Classes	Description
1	Rang Land Area	Areas characterized by natural and semi natural vegetation, open area of dwarf shrubs with herbaceous, and spares shrubs with herbaceous
2	Irrigated Tree Crop	Fruits areas such as, almond, olive, citrus and fig, also vegetables areas
3	Bare Soil	Characterized by sandy soil and dominated by non-natural vegetation
4	Urban Area	Characterized by *Low* Intensity Residential, these areas most commonly include single-family housing units and population densities lower intensity residential areas
5	Quarry area	Areas of extractive constructed materials

6.3.4 change detection of land cover area (Quantitative)

Change detection is a technique that can be defined as "the process of identifying differences in the state of an object or phenomenon by observing it at different times" (Singh, 1989). Another definition from Macleod, *et al.* (1998) is "change detection is a technique used to determine the change between two or more time periods of a particular area".

There are several methods for the determination of change, but basically, there are two main approaches, comparative analysis of independently produced classifications and simultaneous analysis of multi-temporal data (Singh, 1989). The post-classification comparison method for change detection is one of the common methods least affected by differences in image characteristics used in the change detection. It is also rather straightforward for implementation producing relatively acceptable results (Foody, 2002).

Four Landsat TM images were analysed to determine any land cover class occurring in the study area. Many of the classes were repeatedly detected in the time series of images and the changes of the area can be distinguished between the periods of time. In this study, changes in size (in hectare) for each class were identified over 13 years, from 1988 to 2000, with five-year intervals. The size for each class that was detected is shown in Table 6.5.

Land cover classes	1988 Area (ha)	1992 Area (ha)	1996 Area (ha)	2000 Area (ha)
Bare Soil	13829.9	28115.370	28341.990	25995.780
Range land	70166.9	80250.210	77592.150	97864.740
Irrigated Tree Crops	53881.6	47485.710	48474.090	41053.230
Urban	1689.57	3007.080	4316.580	6920.460
Quarry	27325.3	8034.750	8168.310	169.560

Table 6.4. Area (in hectare) of land cover classes from 1988 to 2000

Through the result shown in Table 6.4, the area change (size) for each land cover class in the study area can easily be detected. To get a better view of the changes, the results have been illustrated in graphs shown in Figure 6.12 to 6.16, Figure 6.17 to 6.25 where the classes have been draped over Landsat TM 321 (RGB) images which represent the changes areas through 1988 – 2000, supported with some photographs, Figures 6.24 – 6.25.

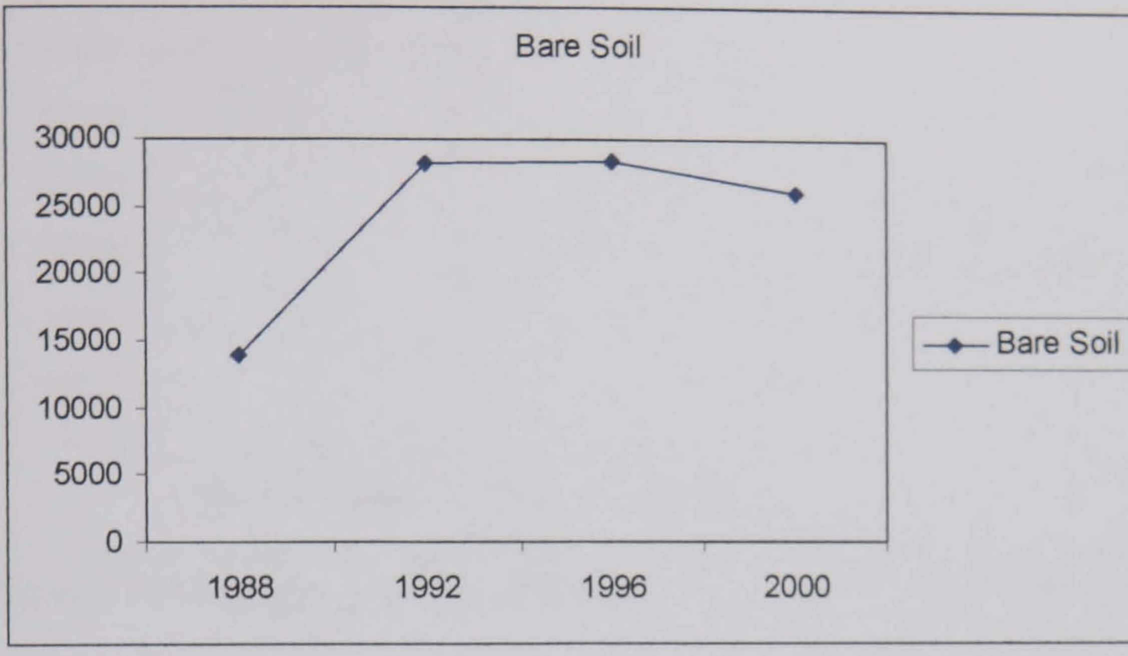


Figure 6.12.Changes of bare soil class area (ha) from 1988 to 2000

Figure 6.13.Changes of rangeland class area (ha) from 1988 to 2000

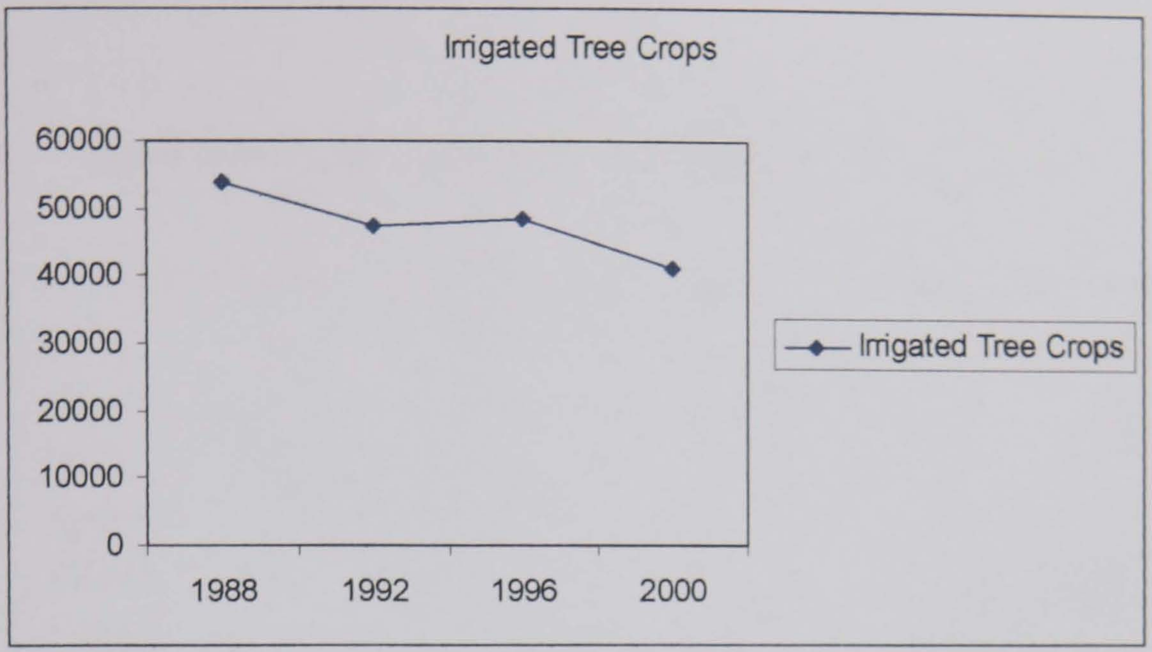


Figure 6.114.Changes of irrigated tree crop class area (ha) from 1988 to 2000

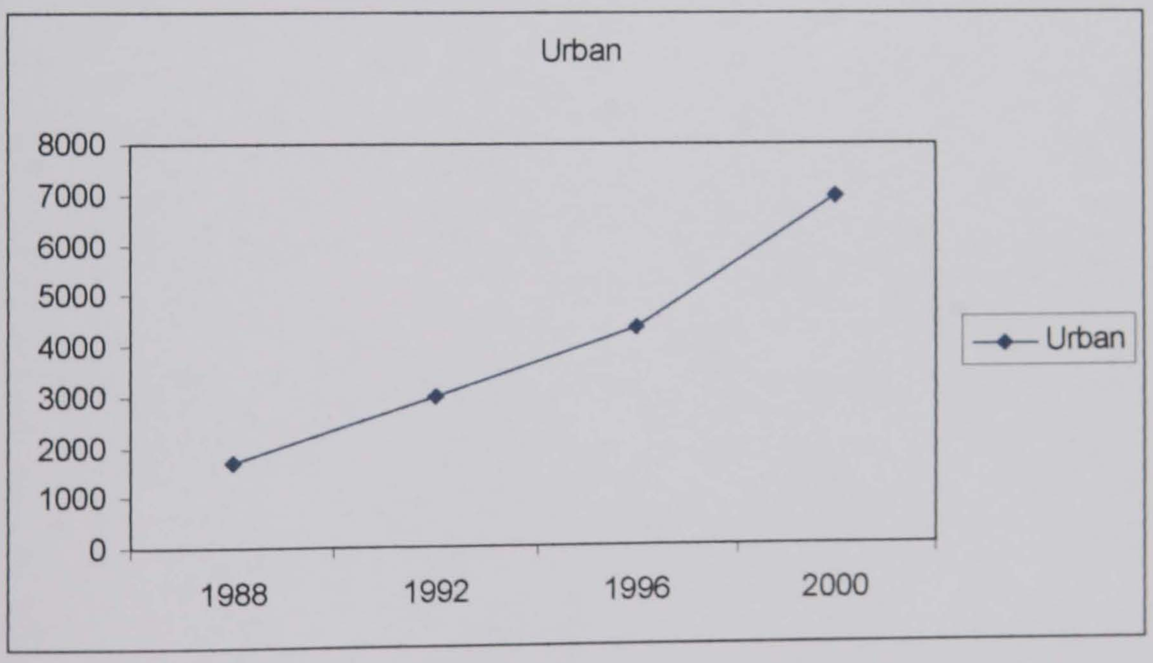
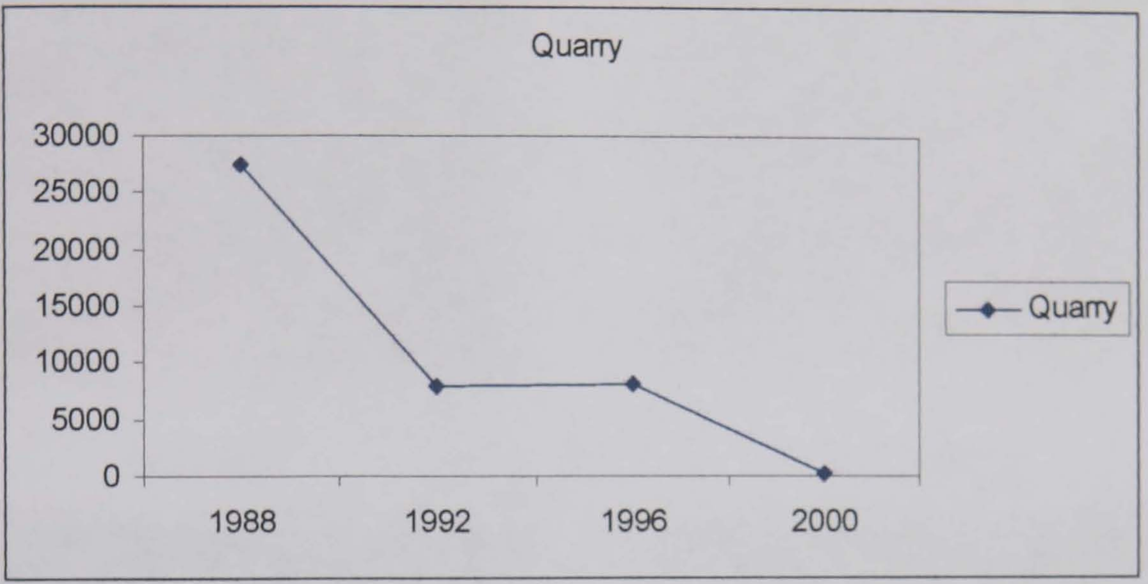


Figure 6.15.Changes of urban bare soil class area (ha) from 1988 to 2000

Figure 6.16.Changes of quarry class area (ha) from 1988 to 2000



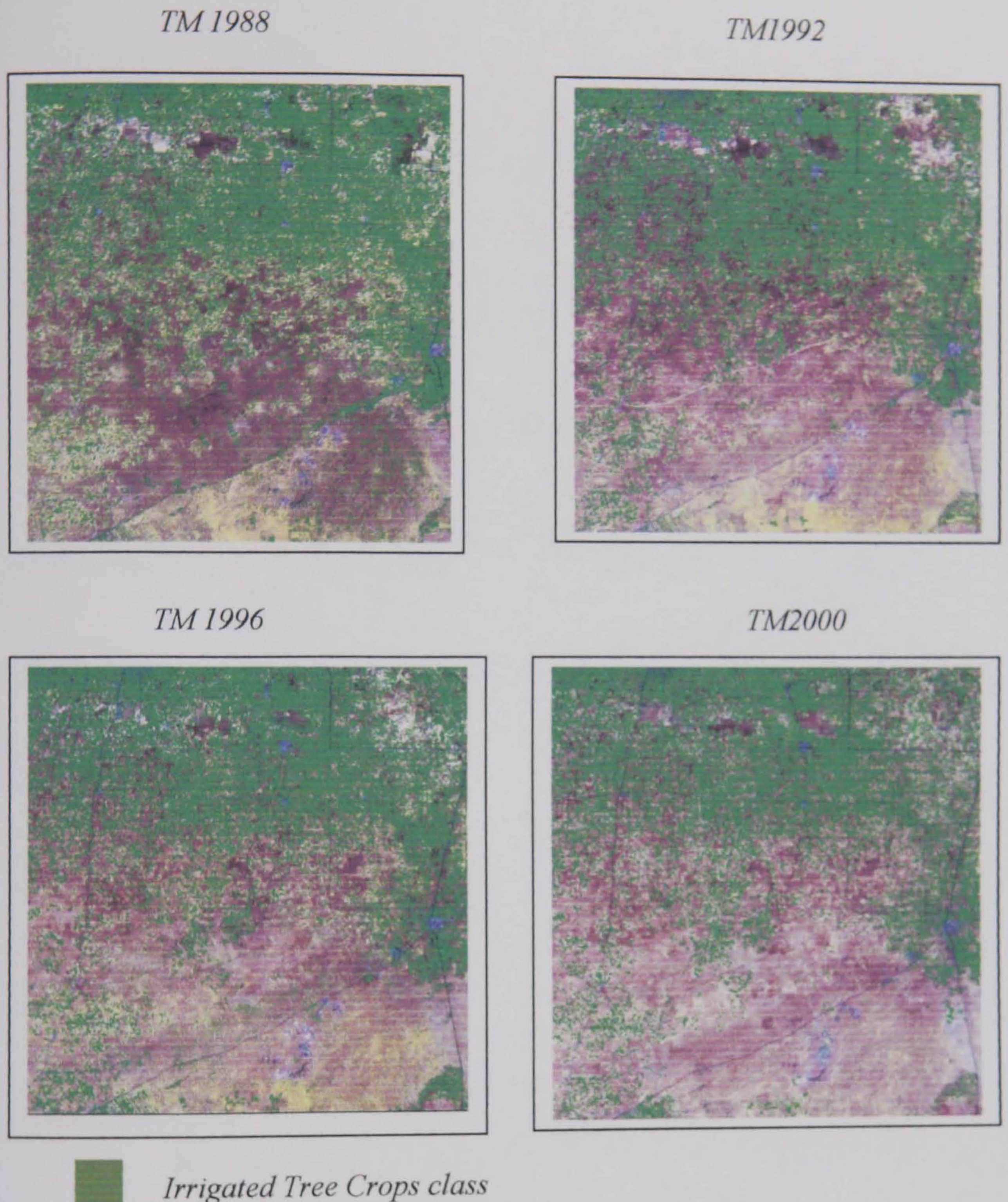


Figure 6.17. Irrigated Tree Crops class draped over the Landsat TM bands 123 RGB

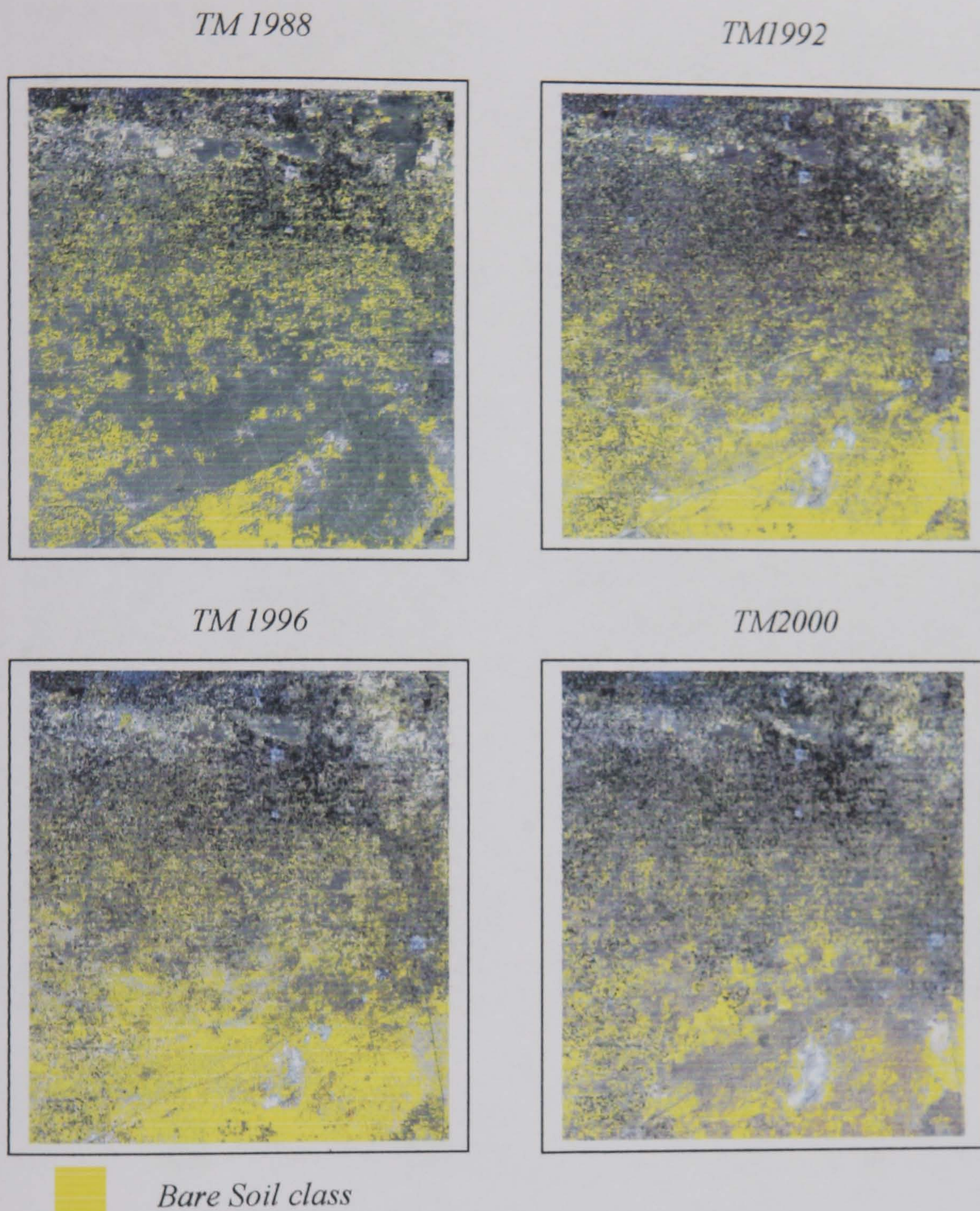


Figure 6.18. Bare Soil class draped over the Landsat TM bands 123 RGB

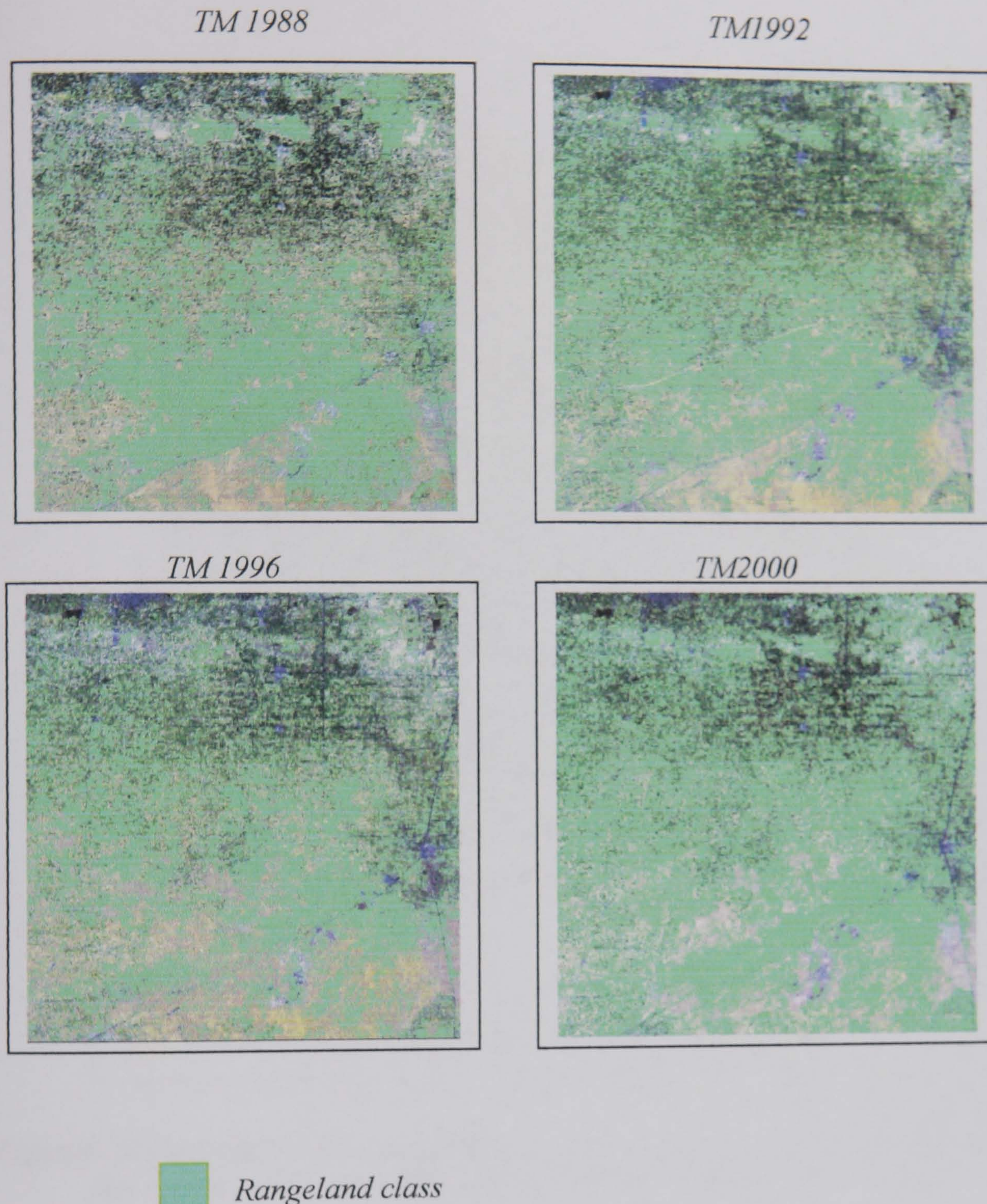


Figure 6.19. Rangeland class draped over the Landsat TM bands 123 RGB

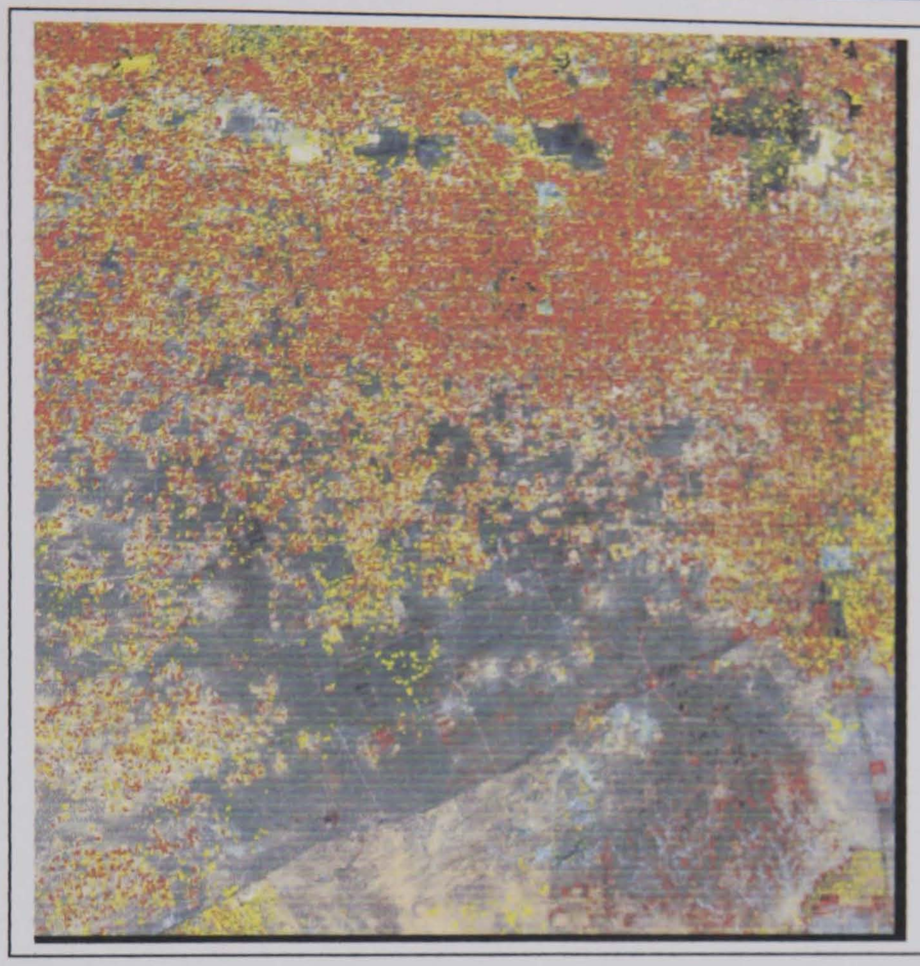
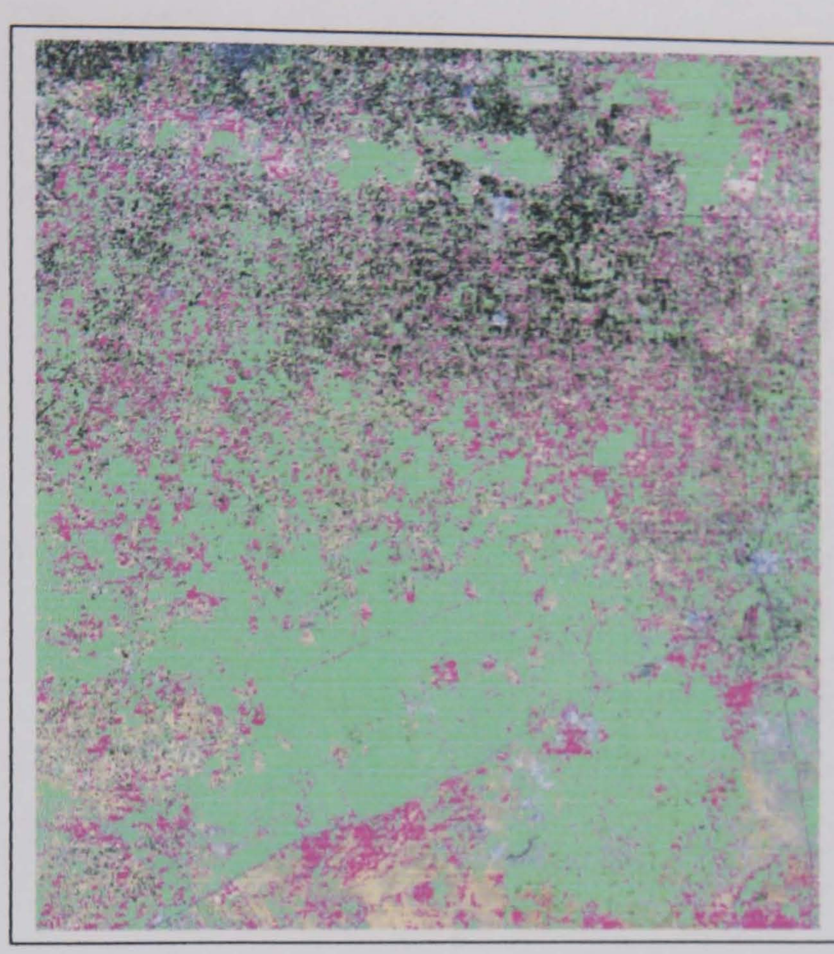


Figure 6.20 Decrease of areas of Irrigated Tree Crops class in 2000 compared with the same class in year 1988 draped over TM 1988 (band 321 RGB)



Rangeland class in 1988

Increase areas of Rangeland class in 2000

Figure 6.21. Increase areas of Rangeland class in 2000 compared with the same class in year 1988 draped over TM 1988 (band 321 RGB)

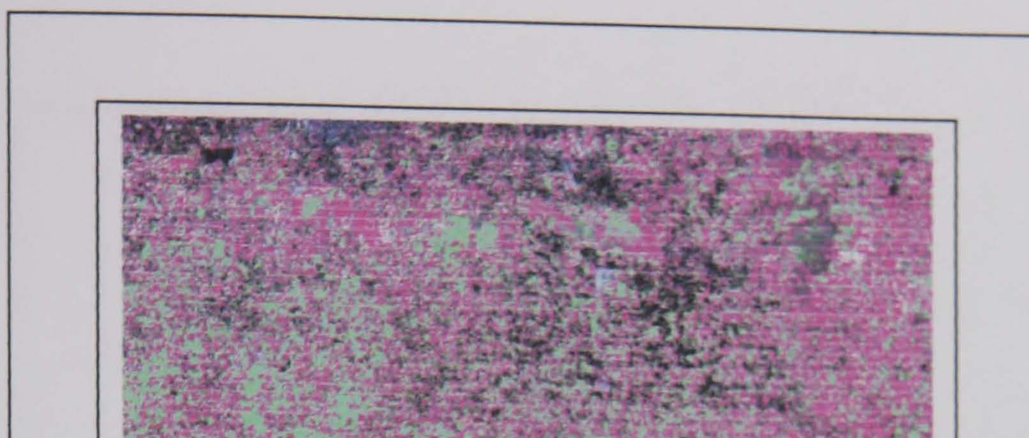


Figure 6.22. Increase areas of Rangeland class in 2000 compared with the same class in year 1996 draped over TM 1988 (band 321 RGB)

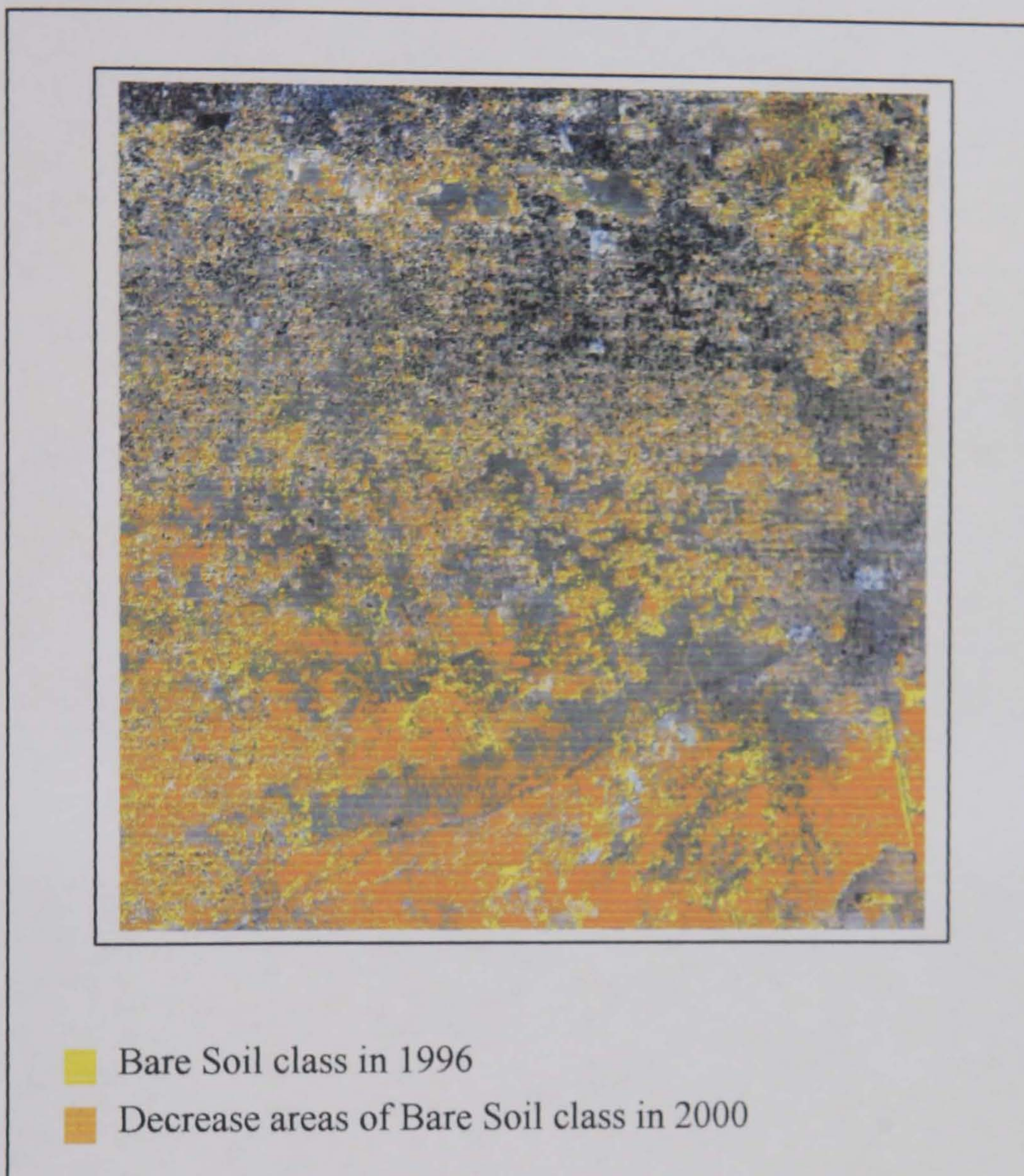


Figure 6.23. Decrease areas of Bare Soil class in 2000 compared with the same class in year 1996 draped over TM 1988 (band 321 RGB)

Figure 6.24, (A & B). Photographs shows of Bare Soil class (Land conversion).

Figure 6.25, (C & D). Photographs shows of rangeland class (overgrazing).

6.4 Results and discussion

6.4.1 Land cover mapping

Supervised classification was used in this study, and five land cover maps were successfully created. Overall accuracy for all maps was more than 80% (Table 6.2). The accuracy of the map is an important factor to ensure further analysis is valid and useful. It is difficult to have high accuracy of a land cover map if the area involved is huge.

6.4.2 Land cover changes

This chapter presented the potential of using remotely sensed data as a resource for mapping and detecting the changes of land cover in arid/semi-arid environments, via digital image processing procedures to create land cover maps and its changes by using Landsat TM. During analysis, five of the land cover classes were successfully defined in the study area from five Landsat (TM) images. Some of the classes were directly related to those which existed naturally in the area, some classes were named according to its activity, since the sizes of these areas were sufficient, they can be clustered independently to be their own class. These classes can be used to investigate the agricultural activity or identify the progress of development stages.

Comparison of classes in year 2000 with 1988 found increased areas in Range Land and Urban classes but at the same time a decrease in all area of other classes. But it can be clearly seen that in 1996 all the classes were stable compared with 1988. In 1992, most of the classes increased in area except Irrigated Tree Crops and quarry area. In fact the largest changes that happened between years 1996 2000 were Range Land class increase of about 20,000 ha but at the same time a decrease in Bare Soil class area. (See figures 6.22, 23)

These changes can easily be detected through visual interpretation of the land cover map shown in Figure 6.19 and Figure 6.20. They show that the two types of land cover classes are changing between each other in the same area. This situation suggests that classes produced via satellite imagery are more expected to indicate the information of land cover rather than the land use. In addition, without spatial information, the changes and the relation between classes cannot be revealed correctly.

In conclusion, supervised classification of Landsat TM imagery was successful for creating land cover maps and detecting changes of land cover through the 13 year period of time 1988 to 2000, which show the distribution and changes of land cover in the study area. According to the analysis and results of this study, the dynamics of the land cover changes that occurred in the study area resulted from many factors such as unsuitable use of marginal land, removal of natural vegetation, climate (arid), scarcity of rainfall and ground water deterioration, These factors caused active wind erosion and led to desertification in the study area. This type of change detection procedure can help to evaluate the changes that have occurred and will help to develop the indicators of desertification. The information which has been extracted from remote sensing data will be integrated with other data sets in a GIS to establish such a model for develop indicators of desertification, which will lead to the production a maps of areas vulnerable to desertification.

CHAPTER SEVEN

VEGETATION MAPPING AND MONITORING

7.1. Introductions

One of the greatest problems in the remote sensing of desert vegetation is that reflectance from soil and rock is often much greater than that of the sparse vegetation, making it difficult to separate out the vegetation signal. Huete (1988) developed the Soil Adjusted Vegetation Index (SAVI) to account for these soil effects in areas of low vegetation cover. However, SAVI, as well as other vegetation indices, is simply a measure of the relative abundance of vegetation and gives no indication of the species composition of the vegetation cover. Some of the specific problems involved with remote sensing of arid vegetation include multiple scattering of light (nonlinear mixing) between vegetation and soil (Huete, 1988; Ray & Murray, 1996).

This chapter is supplementary to the previous chapter but focuses on vegetation cover, Eolian Mapping (EM) and vegetation changes in the period of time from 1988 to 2000 using Landsat TM as the source of data to generate the Soil Adjusted Vegetation (SAVI) Index. In regard to the objective of this study, which is to map areas vulnerable to desertification, this led to the definition of degrees of vulnerability for each type of land degradation such as vegetation degradation and wind erosion. There are many factors which influence the amount of wind erosion that occurs. Two critical factors are the percentage of vegetation cover and the type of surface soil. Using satellite digital multispectral data, a simple model has been developed that allows an image to be generated that emphasizes areas with low vegetation density and high reflectance soils. Generally, this created maps two important eolian erosion parameters (i.e., amount of vegetation cover/density). In arid and semi-arid environments, the soils most vulnerable to wind erosion usually have low vegetation cover.

7.2 Methods

The usual way to create vegetation maps is to use the raw bands of digital data in the classification process. But the statistical similarities of vegetation spectral responses, spatial resolution of data and presence of similar species sometimes do not allow the desired results to be obtained from the original bands (Domac *et al.*, 2004).

In this study, all images were standardized to account for differences in atmospheric effects, radiometric calibration, scene illumination, and image registration. These processes already have been described in chapter six. The soil background effects in change detection have been minimized by the use of SAVI. As a first step in this study, the algorithm classification technique has been used to map vegetation of various densities. In the second step, the Landsat TM images were classified to give the actual vegetation over the entire study area using SAVI. The third step used the image difference technique to calculate the changes and the trend of the changes between 1988 and 2000. In this way, our ability to map sparse desert vegetation over large areas has been enhanced by the use of the SAVI index.

7.2.1 Mapping vegetation of various densities

Four digital satellite images (Landsat TM) were used to generate the soil-adjusted vegetation index (SAVI) images: TM 1988, TM 1992, TM 1996 and TM 2000. The SAVI was calculated using channels 3 (red band) and 4 (near-infrared band). According to Huete (1988):

$$SAVI= \frac{P_{NIR} - P_{red}}{P_{NIR} + P_{red} + L} (1+L)$$

Where L is a constant soil adjustment factor which is been used to reduce the soil background effect, P_{NIR} (near-infrared band) and P_{red} (red band) Although Huete (1988) found the optimal adjustment factor to vary with vegetation density, he suggested the use of a constant value (L=0.5), since this reduced soil noise considerably throughout a wide range of vegetation densities. In addition to the SAVI images, the results from vegetation surveys from 2003 and the interpretation of high-resolution satellite data (SPOT-5, IRS-1C/PAN and SPOT-4) of the study area were analysed for further information about vegetation cover. Classification using the following algorithm was used to specify four vegetation indices (SAVI) that fall between 0.1 to 0.9 to map vegetation of various densities over the study area as follows;

a) Low vegetation densities index between 0.1 - 0.2

b) Moderate vegetation density index between 0.2 - 0.3

c) High vegetation density index between 0.3 - 0.4

d) Very high vegetation density equal to or greater than 0.4

The classification layer which computes the soil-adjusted vegetation index (SAVI) has a conditional IF ... THEN ... ELSE statement, and the follow formulae have been used to generated the vegetation classes by means of the SAVI index:

a) if ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5) > 0.1) and ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5)< 0.2) then 255 else null

b) if ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5)> 0.2) and ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5)< 0.3) then 255 else null

c) if ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5) and ((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5)< 0.4) then 255 else null

d) if((I1 - I2) / (i1 + i2 + 0.5)) * (1.0 + 0.5)> 0.4) then 255 else null

Where; I1 = (NIR band), I2 = (red band), i1 = (NIR band), i2 = (red band), and L = constant soil adjustment factor

The resulting four classes are shown in figure 7.2 as follows:

a) Very high vegetation density

b) High vegetation density

c) Moderate vegetation density

d) Low vegetation density

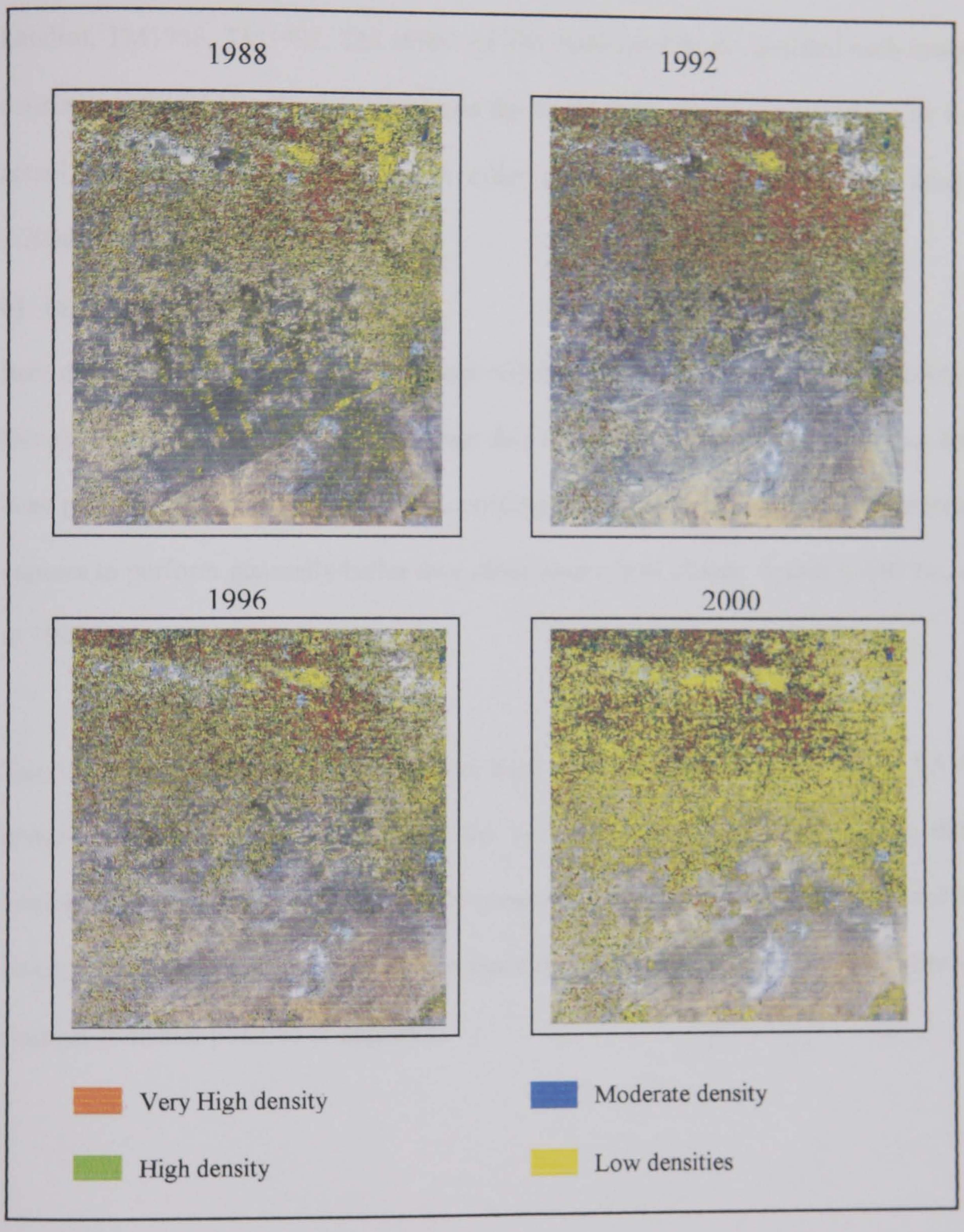


Figure (7.1) various vegetation density classes in years 1988, 1992, 1996 and 2000

7.2.3 Vegetation change detection

a) Actual vegetation classes in the entire study area

Landsat, TM1988, TM1992, TM 1996 and TM 2000 have been classified each image consisting of a SAVI . Figure 7.2, shows the vegetation classes in each image as the actual degree of vegetation cover. In order to monitor vegetation change, image differencing has been used.

b) Image differencing

Image differencing is probably the most widely applied change detection algorithm (Singh, 1989). It involves subtracting one date of imagery from a second date that has been precisely registered to the first. According to recent research, image differencing appears to perform generally better than other methods of change detection (Bauer, *et al* 1994).

Standard digital image differencing was used on a multitemporal dataset of SAVI images to determine the overall and the per cover type trend. All possible date combinations of image differences were generated (see figures 7.3 to 7.8) in order to investigate when the changes had taken place during the twelve-years and the type of changes (whether positive or negative).

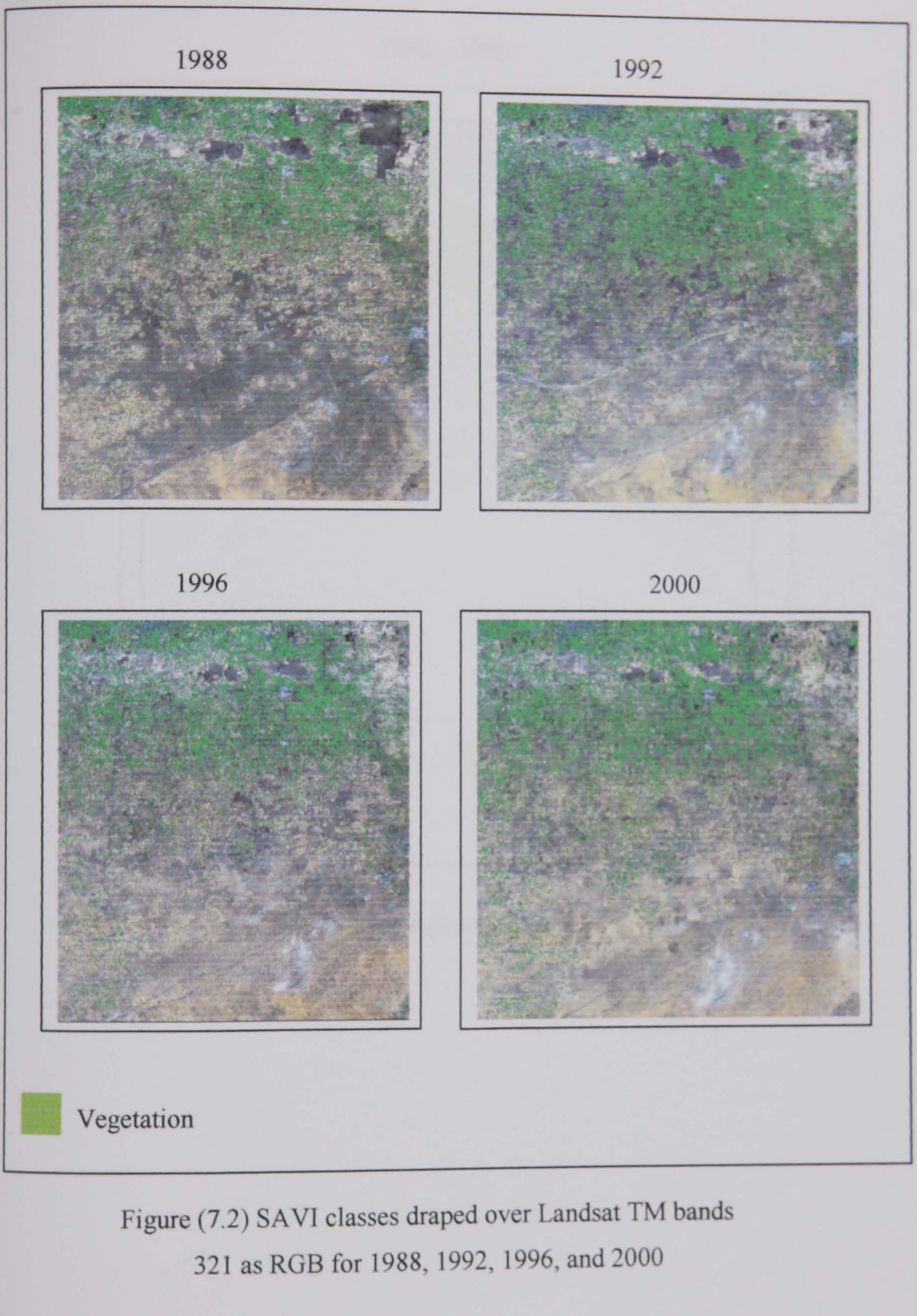


Figure (7.2) SAVI classes draped over Landsat TM bands 321 as RGB for 1988, 1992, 1996, and 2000

1992 – 1988

Figure 7.3 Changes of (SAVI) between 1992 - 1988

1996 –1988

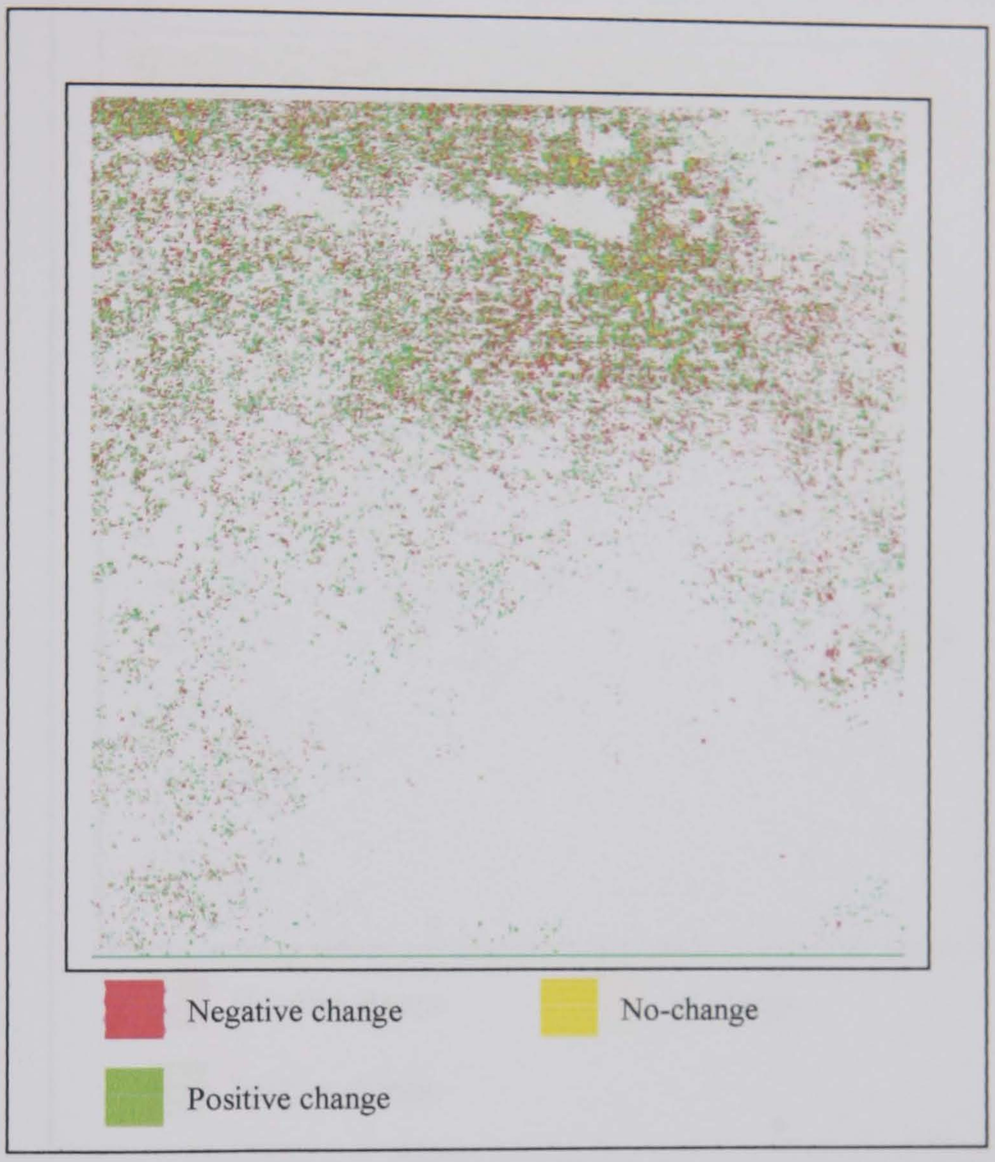


Figure 7.4 Changes of (SAVI) between 1996 - 1988

2000 –1988

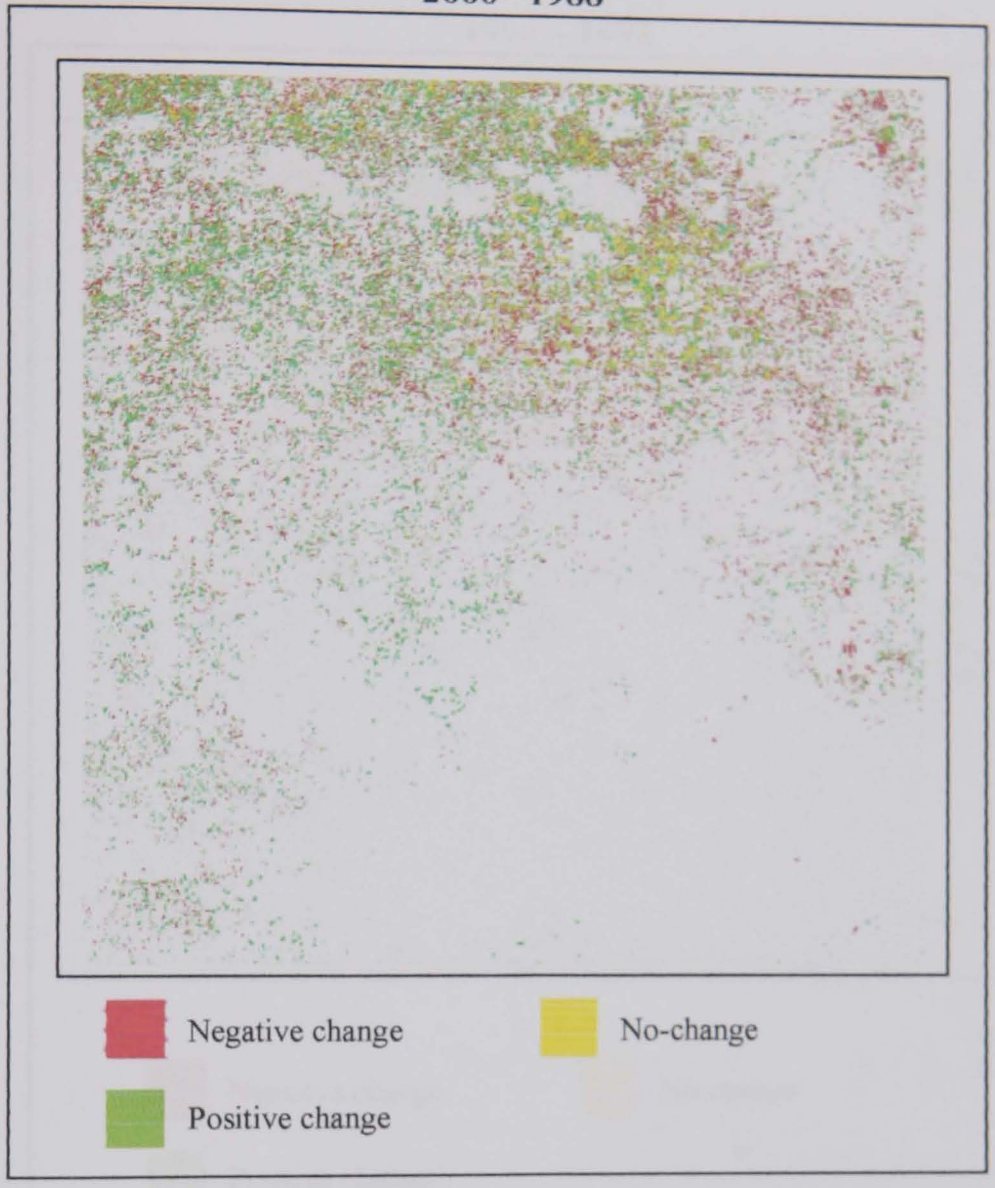


Figure 7.5 Changes of (SAVI) between 2000 - 1988

1996 – 1992

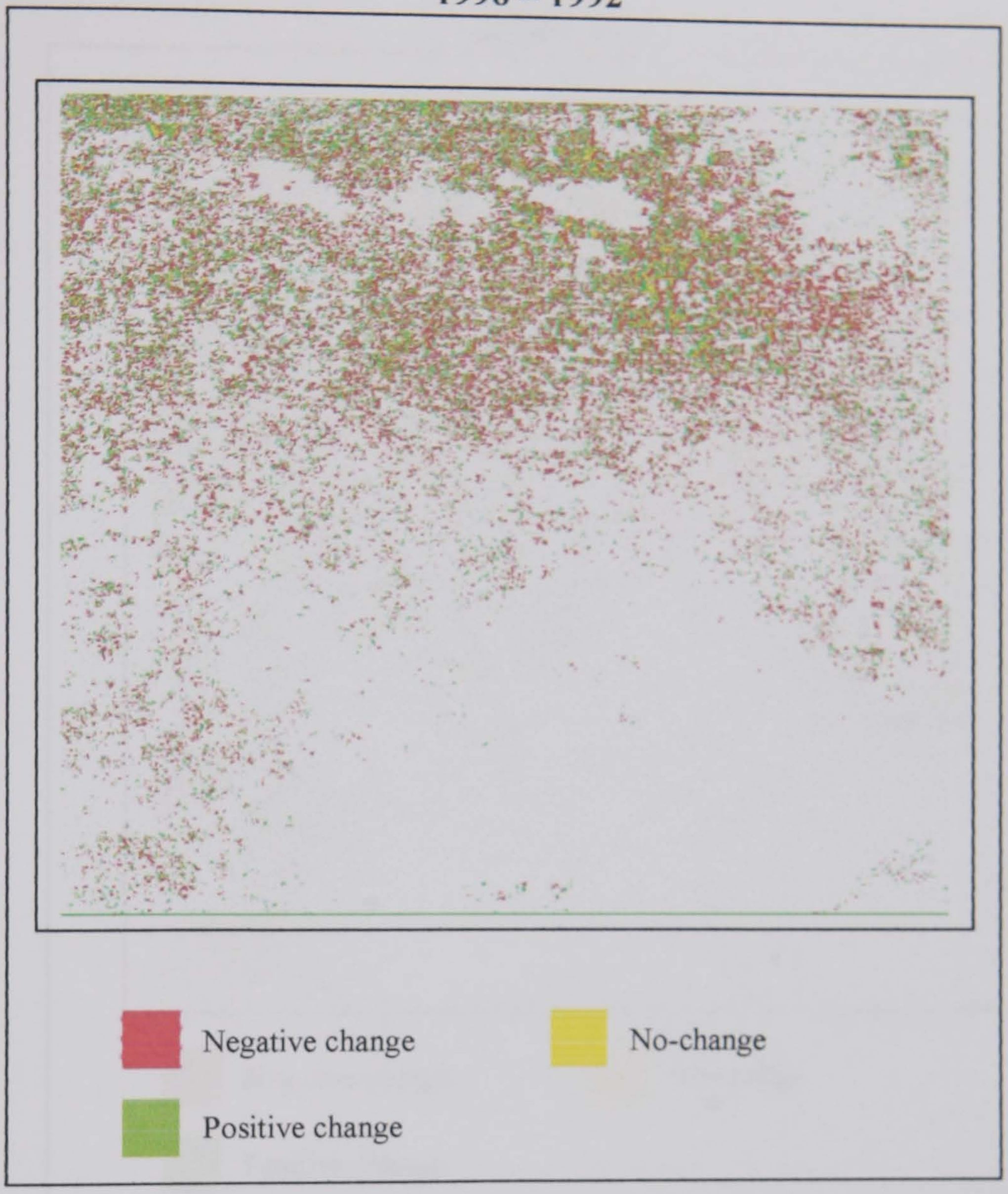


Figure 7.6 Changes of (SAVI) between 1996 - 1992

Figure 7.7 Changes of (SAVI) between 2000 - 1992

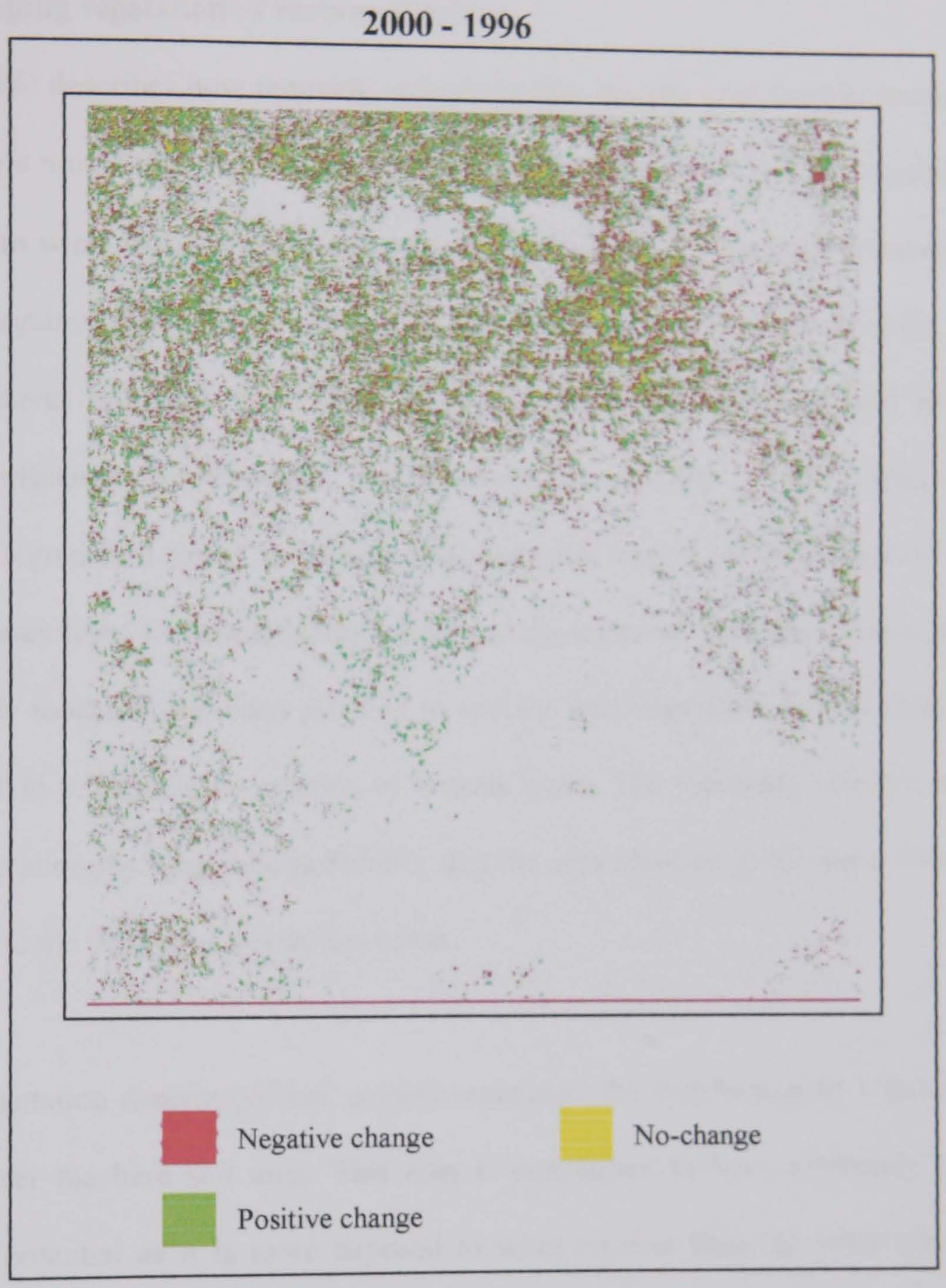


Figure 7.8 Changes of (SAVI) between 2000 - 1996

7.2.3 Results

6.2.3.1 Mapping vegetation of various densities

Chavez (1996) describes how remotely sensed satellite images were used to research and develop a model that can be used to automatically map the level of vulnerability of surfaces to wind erosion in arid and semi-arid environments. Vegetation provides protection against degradation processes such as wind erosion. Destruction of vegetative cover on sandy lands has led to widespread wind erosion, and many indicators influence the amount of wind erosion that occurs. In this study, the vegetation degradation factor is an important indicator and is used to evaluate the areas' vulnerabilities to desertification. Using multi-temporal remotely sensed data and a simple model, it has been possible to specify four vegetation indices that fall between 0.1 to 0.9 to map vegetation of various types. The following analysis took into consideration the range and possibility that the area exposed to the wind erosion was related to the density of vegetation cover.

a) Low vegetation density (yellow colour) represents the distribution of vegetation cover over the bare soil area. This area is considered to have extremely high erosion potential as it is more exposed to wind erosion than the other classes. From results we can see clearly the percentage distribution of areas during the periods of time, 55.5% in year1988, 46.4% in year 1992, 54.9% in year 1996 and 64.5% in year 2000.

b) Moderate vegetation density (Blue colour) represents the distribution of vegetation cover over the bare soil, rangeland area. This area is considered to have moderate erosion potential to wind erosion. From results we can see the percentage distribution of vegetation cover areas during the periods of time, 22.9% in year1988, 25.2% in year 1992, 22.7% in year 1996 and 19.1% in year 2000.

c) Very high density and high-density classes (Red and Green colour) represent the distribution of vegetation cover over irrigated tree crop area. This area is considered to be less exposed to erosion potential and to wind erosion than the other classes because vegetation cover provides protection against degradation processes such as wind erosion. From results we can see the percentage distribution of vegetation cover areas during the period of time

The SAVI images were used to identify vegetation areas in the study area. Obviously, SAVI images alone are not capable of distinguishing different vegetation types, but it is possible to monitor the actual degree of vegetation cover. This can be a great advantage because vegetation classification and description by different authors of the same region can be extremely variable.

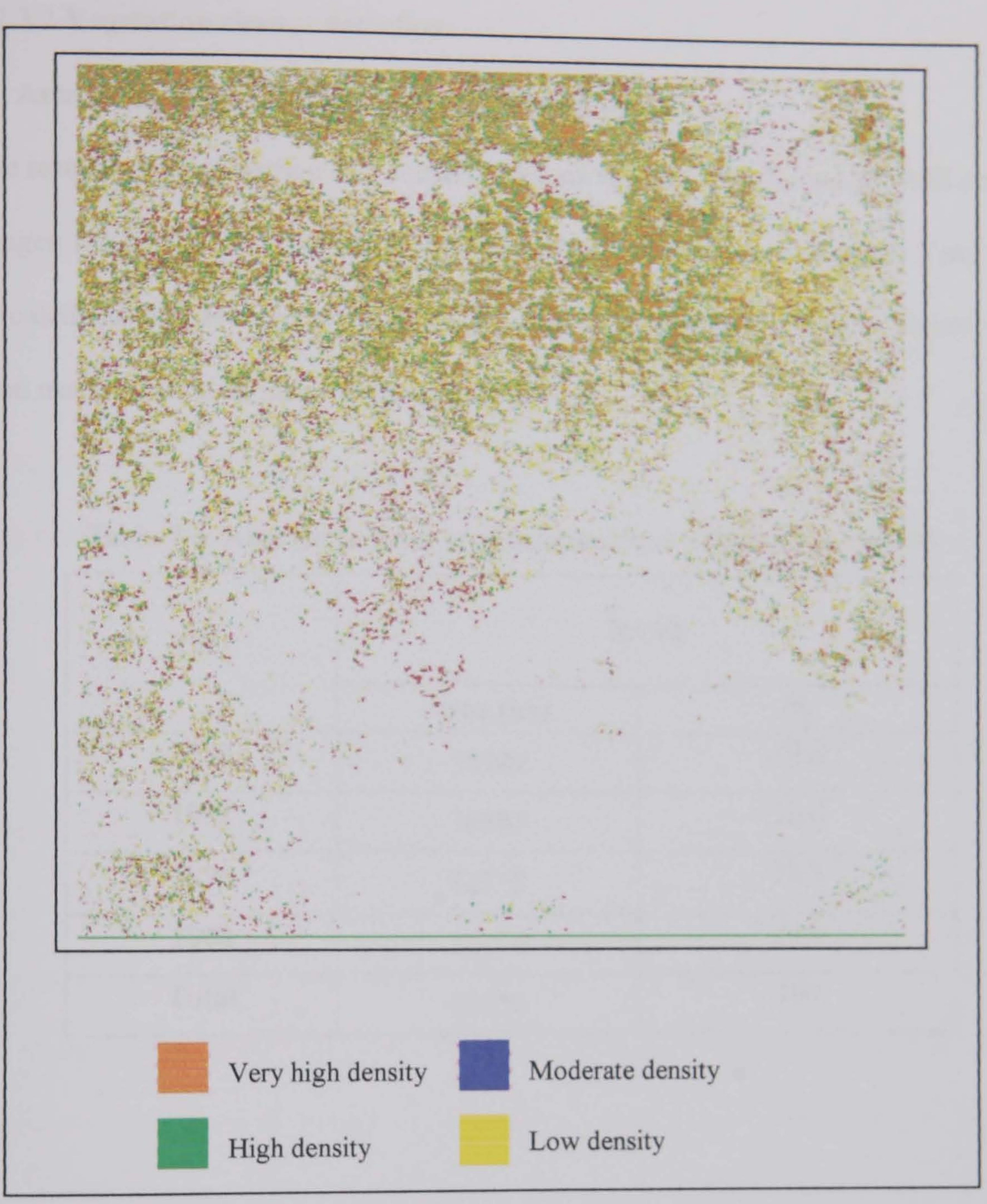


Figure 7.9. Area of various vegetation density classes

7.2.3.2 Vegetation change detection

a) Actual vegetation cover classification analysis

The results of classification as a actual degree of vegetation cover using SAVI created images for all the years which reflect the actual vegetation cover areas. Year 1992 revealed the highest area while 1988 the lowest (see table 7.1), these classes have been used to create an image difference approach.

Table 7.1: Area (in hectare) of vegetation classes from 1988 to 2000

Year	**SAVI**	
	Area (ha)	**%**
1988	10349	19.8
1992	16807	32.0
1996	12178	23.3
2000	13016	24.9
Total	52350	100

b) Image difference approach

– Overall Difference

The overall trend is positive in all difference image-year combinations except for the 1996 minus 1992 and 2000 minus 1992 case. This shift is seen in Figure 7.7 where two is a negative trend from 1992 to 2000, and a positive trend between 1988 and 2000 for all years analysed. Although a positive trend was detected from 1988 to 1992, 1988 has a positive trend when compared to every other year. Inspection of results reveals the highest absolute change in image combinations in which 1996 is subtracted from 1992. This shows that 1992 was the "greenest" of the imagery of the selected four years. Since image difference combinations including 1996 minus 1992, 2000, and 1992 reveal a negative trend and combinations including 1992 minus 1988 reveal a positive trend, 1996 is the least "green" of the years.

7.2.4 Conclusion

The results which have been obtained from mapping vegetation of various densities by classification using SAVI, show areas that have vulnerability to wind erosion susceptibility. This is therefore one land degradation factor that can be created from remotely sensed data.

The results of vegetation trend detected here cannot be extrapolated to changes in species composition. Overall image difference as well as cover type image difference results in VI values (e.g. biomass) and not necessarily species composition change.

SAVI images can be used to estimate productivity (Tucker *et al*, 1985). Vegetation cover type difference images (Figures 7.3 to 7.8) can be used to provide information for desertification prediction. Cover type difference images reveal areas of certain cover types that have increased or decreased in biomass since 1988. This knowledge can be used to determine possible areas of high vulnerability to desertification risk. Finally, the results from this chapter will be integrated with other factors using GIS in the next chapter to produce desertification maps.

CHAPTER EIGHT

GIS AND DESERTFIFICATION MAPPING

8.1 Introduction

According to Calking and Tomlinson (1977), a geographic information system is defined as "an integrated software package specifically designed for use with geographic data for a comprehensive range of data-handling tasks. These tasks include data input, storage, retrieval and output, in addition to a wide variety of descriptive and analysis processes". It is considered to be a mapping system with the capability to record, store, process, manipulate and retrieve data, in order to: (a) digitise maps, (b) overlay spatial data, (c) display information (needed in decision-making), and (d) manipulate attribute information from geographically referenced spatial data. GIS software can be raster (cell-based) or vector-based system.

The advent of satellite imagery, coupled with the collection of spatial data, has helped to demonstrate the impact of desertification and provide the data needed for improving the situation. However, GIS not only allows researchers to view and manage land cover, natural vegetation, soil types, climate, topography, and socio-economic data but also allows them to analyse it all within one framework. GIS is proving a most effective tool for studying this complex phenomenon. In chapters six and seven, the potential for Landsat satellite imagery for providing land cover information over large areas in both spatial and non-spatial forms was discussed, and it will now be integrated and analysed in this chapter. This chapter focuses on two main objectives, the constructing of an integrated GIS database, and developing a criterion for desertification assessment and mapping. To achieve the objectives of this study, land degradation was separated into three types: wind erosion, vegetation degradation, and salinization. The combination of these types will produce an inclusive map for desertification, which will synthesize all types of land degradation.

8.2 Desertification Mapping

8.2.1 Preparation stage of desertification mapping

The compilation of data for desertification mapping requires the following steps:

8.2.1.1 Desertification Mapping Units (DMU)

The Desertification Mapping Unit (DMU) was created via a combination of land units (geomorphology) and land cover types. The land unit map describes the geographic aspects of desertification and the land cover/use map describes the human aspect of the problem. The combination leads to the allocation of a unique value (class) for each possible combination of the two input layer value. Each class is a Desertification Mapping Unit (DMU).

8.2.1.2 GIS database

ArcGIS software has been used to create the GIS database, which consists of many layers, such as a land cover map, a soil map, the slope degree, the geomorphological units, and the rainfall distribution. This database is linked to an attribute database that describes features or polygons on the map.

An extensive GIS database has been built up for the study area using the ArcGIS software through standard procedures including spatial data input, attribute data management, data analysis and data modelling. This database is then used to produce the desertification map

8.2.1.3 Database structure and design

The database management system is a computer based record-keeping frame used by different programs, and allows unification of several distinct sets of data. Most actions on data fall into categories of query, that is, the retrieval of certain instances according to specified conditions, or transaction, changing the specific values in some way, especially via updating existing entries in the database. (Laurini & Thompson, 1998).

The main steps of the database design are to determine the study area bounds, to determine the coordinate system, to identify the required spatial data layers, to determine the required feature attributes, and to define each attribute and its code and coordinate registration.

The study area was determined and the coordinate system to be used is datum *WGS84* and projection *NUTM33* with six spatial data layers being identified which included a feature attributes database. All this data for the assessment of desertification mapping unit will be carried out based on the particular selection criterion. Each selection criterion will then be translated into a specific data layer with specific feature attributes.

8.2.1.3.1 Spatial Database Input

GIS involves both spatial and attribute data: spatial data relates to the geometry of map features, whereas attribute data describes the characteristics of the maps features. Attribute data are stored in tables. Each column represents a characteristic. The intersection of a column and a row shows the value of a particular characteristic for a particular map feature.

The main aim of creating these spatial databases is for linking them with their non-spatial attribute database, thus enabling the analysis to be undertaken interactively between the spatial and non-spatial database. This will also enable the descriptive attribute attached to the geographic features to be displayed and presented in graphic form, (figure 6.1), and to show the data input procedure. In order to manipulate the information of the objects and features in digital form, a digitising process is carried out to create the database layers, which will be processed and analysed. Six database layers were created and stored in a grid data model as follows:

1. **Land cover:** classification of Landsat TM produced five classes. Within this layer the cover of the study area has been identified as the following classes. Irrigated tree crop, Rangeland, Urban, Quarry and Bare soil.
2. **Rainfall:** produces the rainfall map by using the mean yearly rainfall
3. **Salinity:** produces the salinisation map.
4. **Soil:** specifies the soil map, which presents the various soil texture type, Sand, Sandy Loam, Loamy Sandy and Loam.
5. **Topography:** produces the topographic map, which is composed of contour lines.
6. **Vegetation:** classification of vegetation cover classes by SAVI.

8.2.1.3.2 Non-spatial database input

Non-spatial data elements are imported into the ArcGIS software as tabular data. This requires the attribute data to be put into the computer and to associate the attributes with the spatial feature. In order to reference the attributes of the objects in the graphical data, information had to be stored in an attribute table. The procedure for inputting data into attribute tables was carried out in two ways; the data which is automatically generated by the system during the digitising process. And those data, which are used to create shape files

Attribute data management

In this study, three *ArcGIS* applications have been used; *ArcCatalog*™ to make accessing and managing geographic data simple. One can find the data needed, quickly review it and display its contents, as well as read or create metadata. One can also manage spatial data stored in folders on local disks or in relational databases. *ArcMap* to display and query maps, providing an easy and natural transition from viewing a map to editing its geography. *ArcToolbox™* provides an environment for performing geoprocessing operations and many geoprocessing tasks including data conversion.

For database to be useful for spatial analysis, all parts of the database need to have been registered to a co-ordinate system, in this case *UTM, Zone 33* and Datum *WGS 84*.

i) Decision making techniques

To assess the different type of desertification classes, several criteria will need to be evaluated. The combination of these criteria will form a single index of desertification. Such a procedure is called Multi-Criteria Evaluation (Voogd, 1993,Carver, 1991). Multi-Criteria Evaluation (MCE) in this study is achieved by the weighted linear combination (WLC) procedure, where factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map. Then this map is "thresholded" to yield a final decision map. In the present study this led to the definition of three degrees for each type of land degradation: wind erosion, vegetation degradation and salinisation.

8.2.2 Desertification mapping

As discussed previously, land degradation was separated into three types: wind erosion, vegetation degradation and salinisation. The combination of these types will give an inclusive and general degradation map of desertification. The following is a description of each of these processes: Figure 8.1

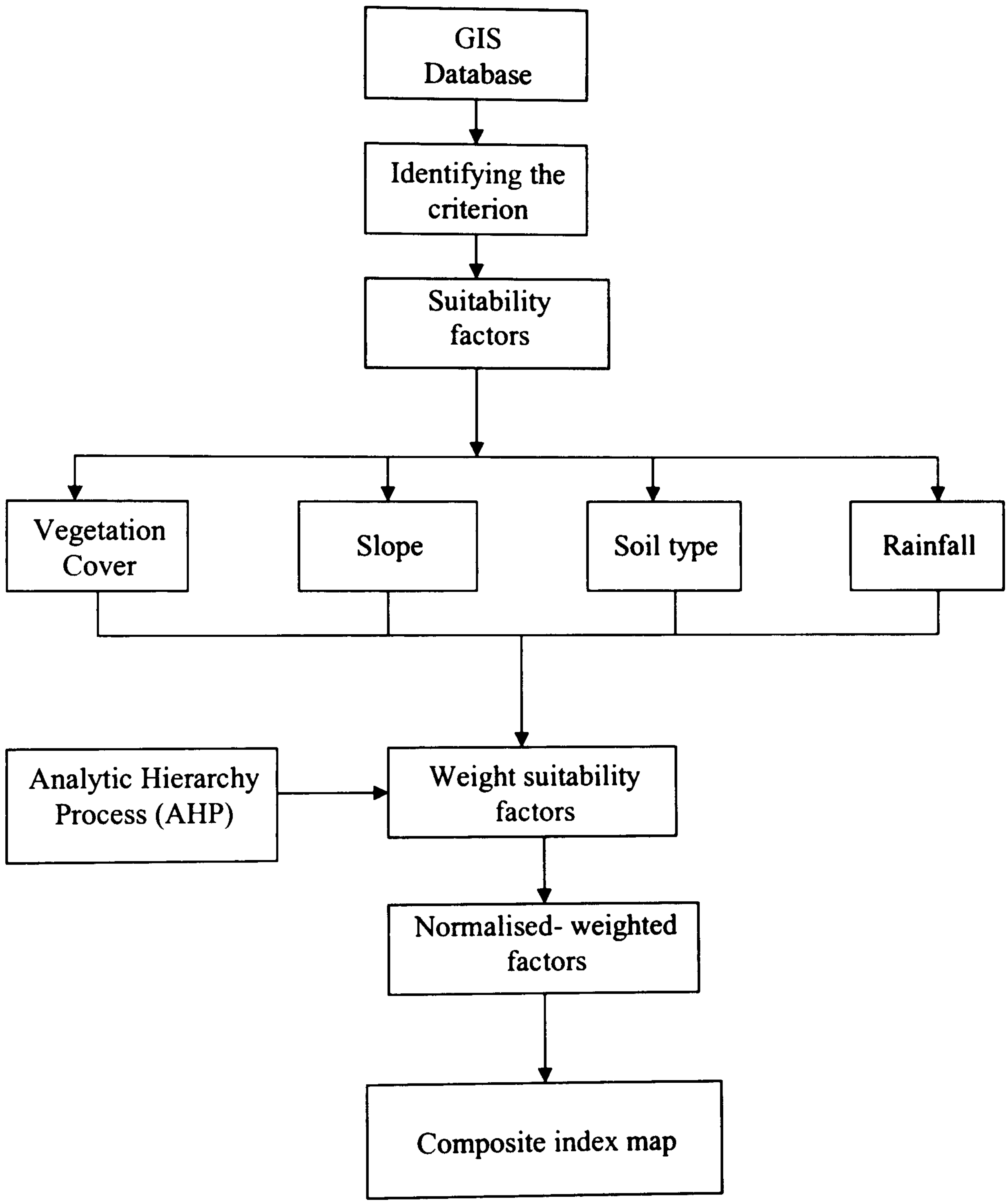


Figure 8.1 Sequential Procedures of the Models Development for Desertification Assessment

8.2.2.1 Identifying Suitability Criteria

The initial step in land suitability analysis is to identify those factors that influence the suitability of land for each type of land cover. An exhaustive list of factors should be carefully prepared to ensure that all influential factors have been taken into consideration. The factors and their criteria are described in the table 8.1.

Table 8.1 criteria of factors of desertification

CRITERIA	GOAL
1. Vegetation cover 2. Soil type 3. Slop 4. Rainfall	Wind erosion
5. Density of Vegetation cover 6. Destruction of Natural Vegetation Cover	Vegetation degradation
7. Water quality 8. Physical Degradation	Soil salinisation

8.2.2.2 Creating land suitability factors

Land suitability is the ability of land to physically sustain or accommodate a certain type of land cover with respect to certain suitability criteria. GIS operations such as overlay and the standard logical operation were used to derive factor coverage from the original database. The process involves developing several intermediate grids on the way to generate single suitability factor grids.

a) Agricultural suitability factors

The land cover map is derived from classified remotely sensed data and converted to grid format in GIS to produce the agricultural suitability map, taking into consideration the factors relevant to the evaluation of wind erosion as follows:

- High: area exposed to wind erosion susceptibility: Bare soil (open space, and sand dune area).

- Moderate: area expose to wind erosion susceptibility: Range land.
- Slight: area expose to wind erosion susceptibility: irrigated crops, quarry land and urban area.

Suitability scores and classes are assigned to this agricultural map. The scores assigned range from 1 to 3 as follows:

1. High venerability
2. Moderate venerability
3. Slight venerability

The bare soil land class was assigned the highest score of 1, as these are considered to be the very highest vulnerable areas exposed to wind erosion. The range land was assigned the score of 2, whereas the lowest score of 3 was assigned to the irrigated crops land, urban and quarry class in the land cover map, as shown in table (8.2).

Table 8.2 the agricultural suitability classes

Land use class	**Most Venerable (1)**	**Moderately Venerable (2)**	**Slightly Venerable (3)**
Irrigated crops land			▪
Bare soil	▪		
Rang land		▪	
Urban			▪
Quarry			▪

Using the suitability classes and agricultural map, an output (map suitable agricultural map) was generated (figure 8.2). The suitability map shows the new classes and scores assigned to each of the classes. Three main classes were generated.

1. High: area highly exposed to wind erosion susceptibility
2. Moderate: area moderately exposed to wind erosion susceptibility
3. Slight: area slightly exposed to wind erosion susceptibility

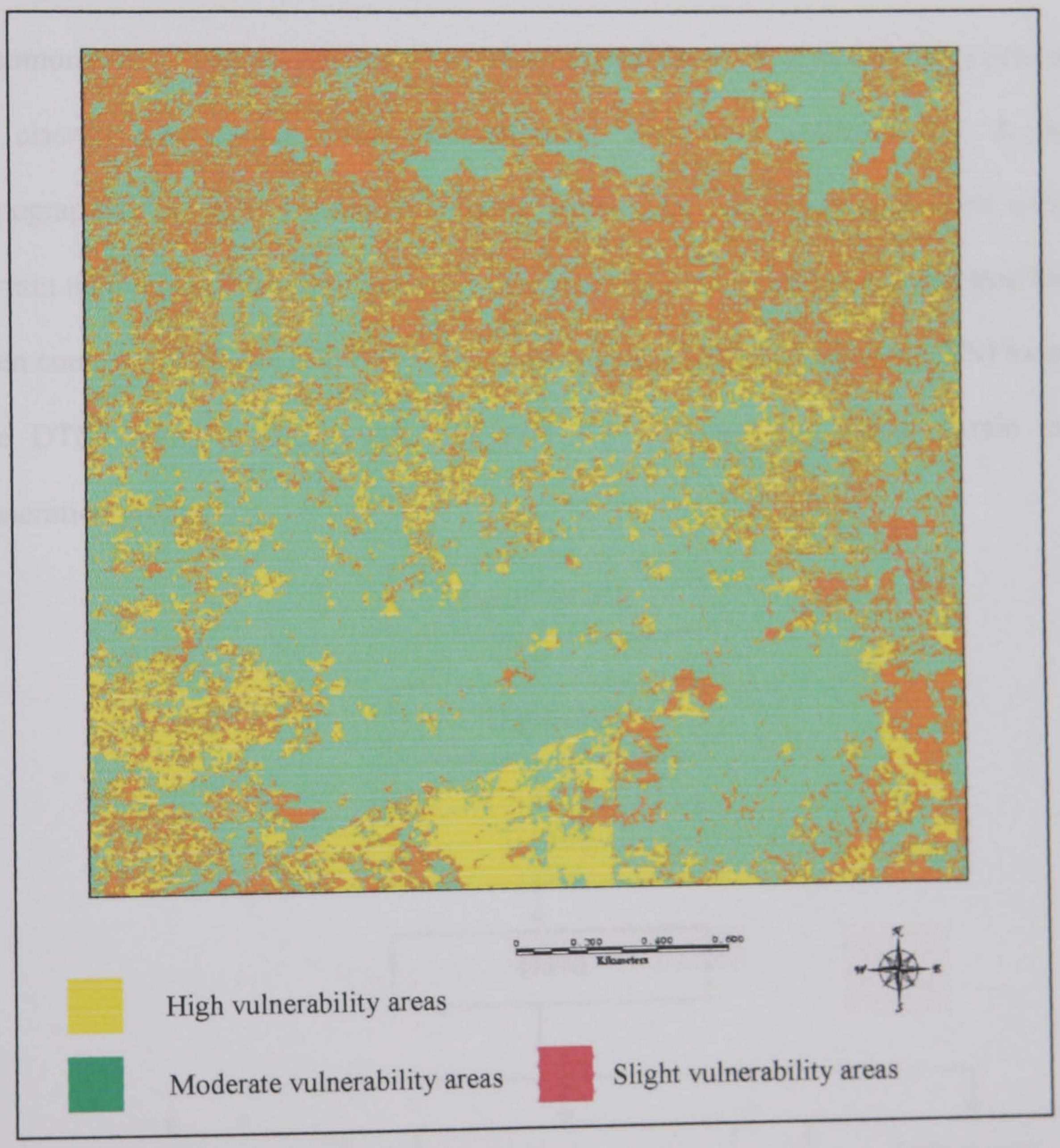


Figure (8.2) agricultural suitability map

- **Slope suitability factors**

To create a slope suitability map there are two main processes which should be undertaken.

- Generating a Digital Terrain Mode (DTM)
- Calculating slopes for identification of suitability map

- ***Digital Terrain Mode (DTM) generation***

Geomorphological units are related to the susceptibility of an area to erosion processes, to classify the area in terms of topography and wind characteristics. A digital topographic map with a 20-metre contour interval has been used to generate a digital terrain model from a contour map using MapInfo software with the contour map format then converted to shape a file to create a Triangulated Irregular Network (TIN) based on the DTM using ArcGIS software. Figure 8.3 illustrates the digital terrain model generation process.

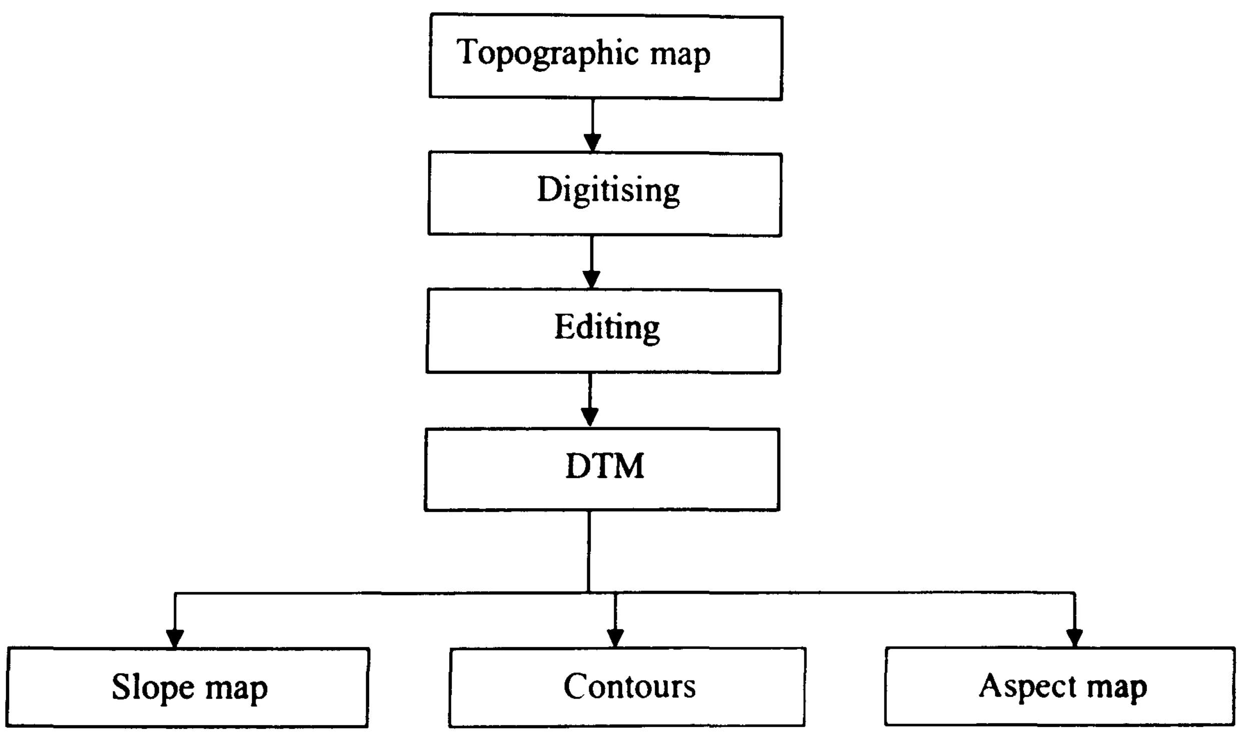


Figure 8.3 The DTM generation process

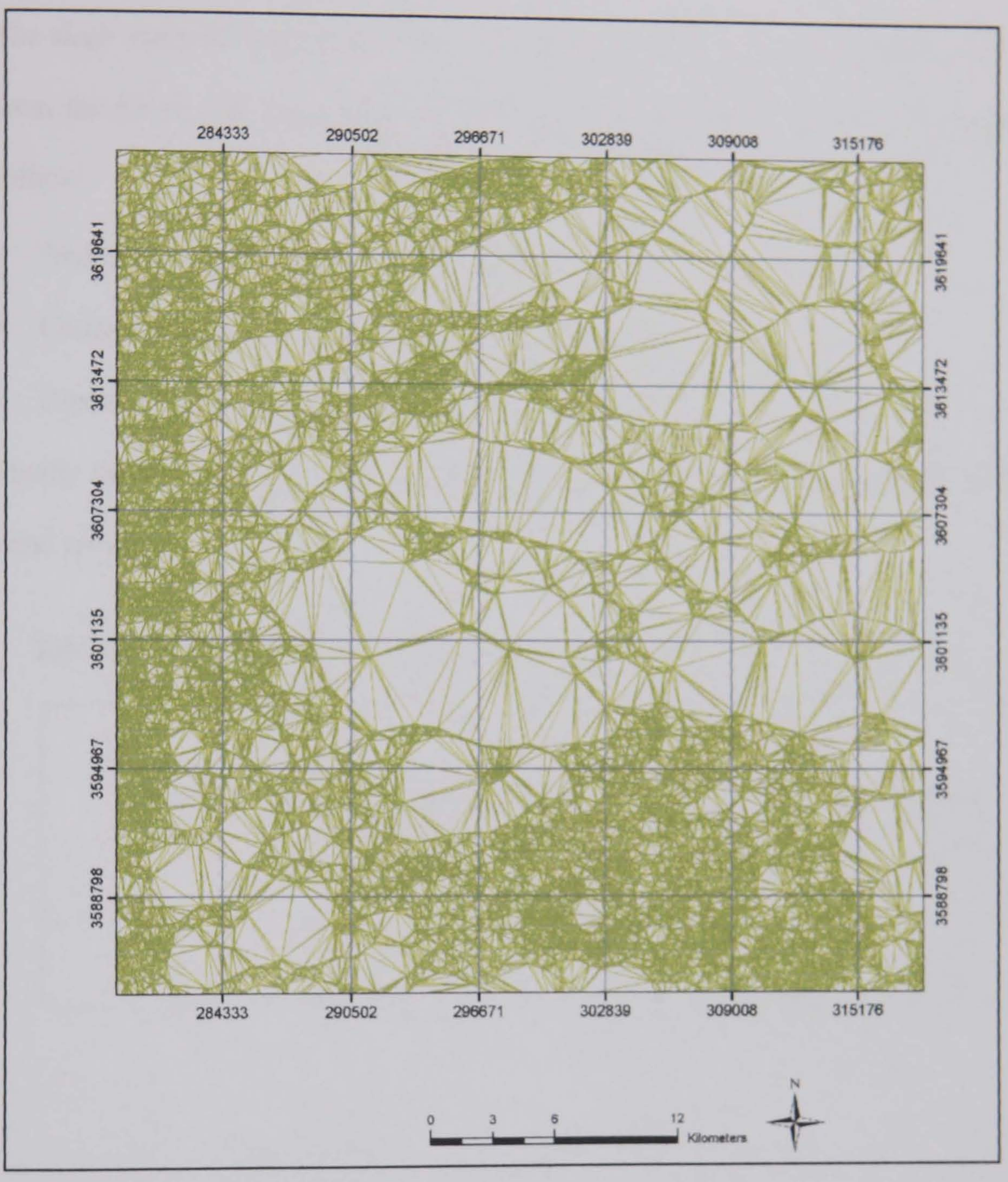


Figure 8.4. Generating a Digital Terrain Mode (DTM)

- **Slope suitability identification**

The slope suitability map was produced from the slope-percent class, which is generated from the DTM. The steps used to generate the slope suitability were summarized as follows:

- Generate TIN-DTM for the entire area
- Create the slope map according to suitability classes.
- Create grid classes of selected slope suitability classes

Finally the classes were selected, high, moderate, and slight as vulnerability areas for wind erosion.

Table 8.3 suitability classes for slope map

Suitability Class	Highly Suitable (1)	Moderately Suitable (2)	Poorly suitable (3)	Slightly Suitable (4)
Slope %	0 -5	5 -7	7 - 10	>7

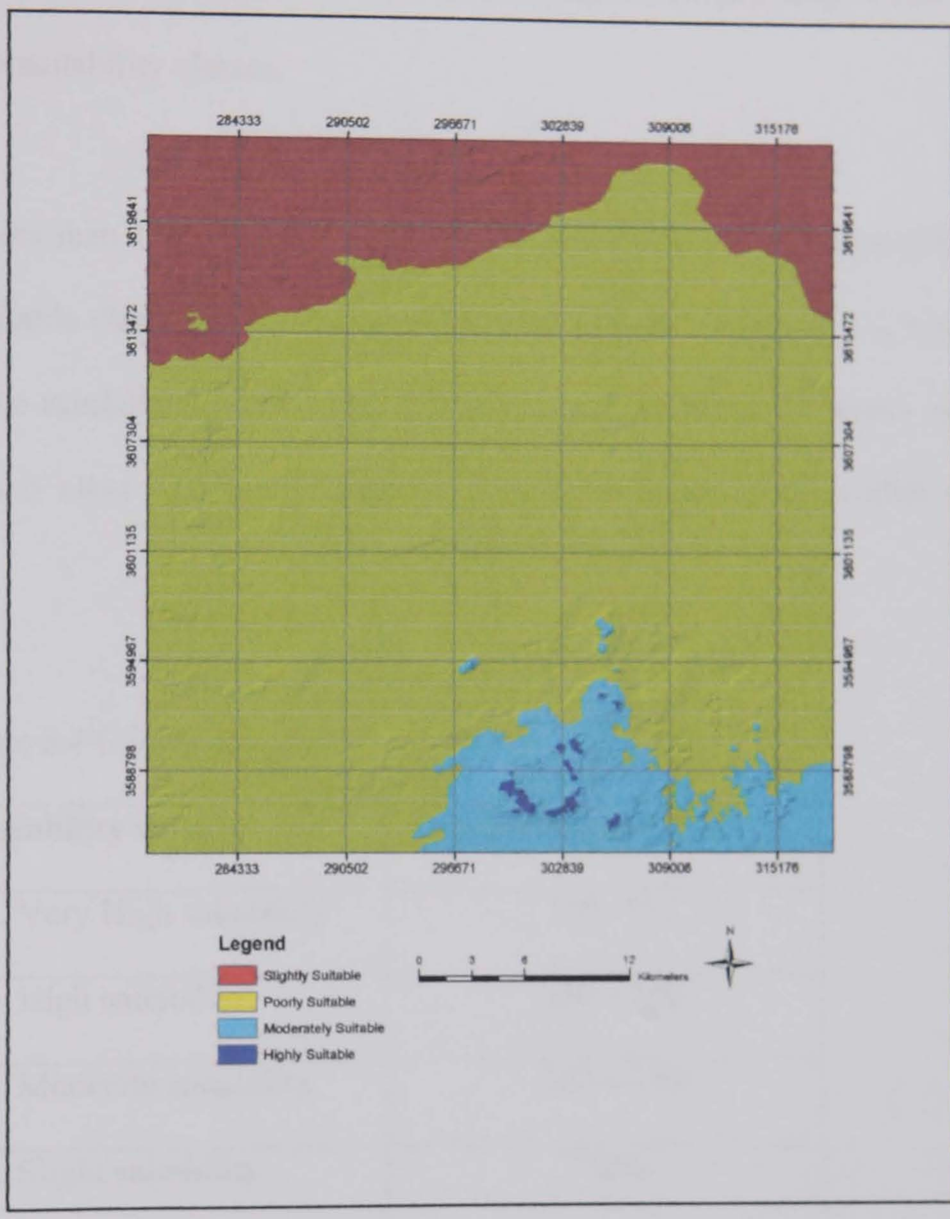


Figure (8.5) slope suitability map

- **Climate suitability factors**

The climate map was produced from the superimposed rainfall and maps. The climate suitability map has been generated by reclassifying the climate map. Table (8.4) shows the climate suitability classes.

Rainfall less than 150mm is given the higher score of 1 which is considered the very highest suitable class. Rainfall between 150 and 200mm has score of 2 which is highly suitable, the rainfall of 200mm and 250 is assigned a score of 3 which is moderately suitable, and class 4 which is slightly suitable, is assigned to rainfall greater than 300mm.

Table 8.4 Climate suitability map classes

Suitability class	**Average Rainfall mm**
1. Very High suitability	100 -150
2. High suitability	150 – 200
3. Moderate suitability	200 – 250
4. Slight suitability	>300

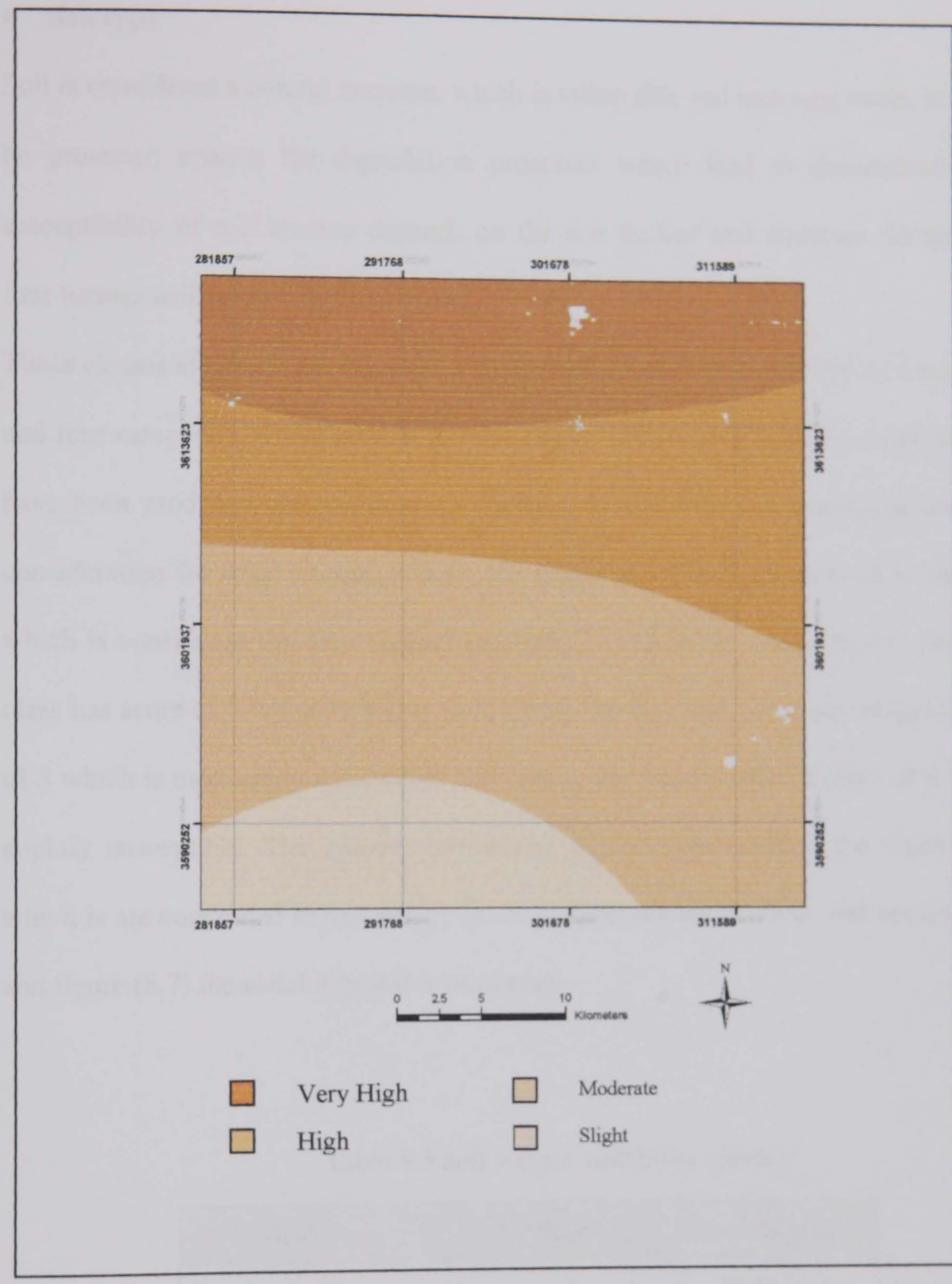


Figure (8.6) climate suitability map

- **Soil type**

Soil is considered a natural resource, which is vulnerable and non-renewable. It needs to be protected against the degradation processes which lead to desertification. The susceptibility of soil erosion depends on the soil texture and structure. In this study, four texture soil classes have been used.

These classes are produced from the soil map based on its susceptibility to wind erosion and four categories of soil texture, namely Sand, Sandy Loam, Loamy Sand and Loam have been produced. To generate a suitability classes for each evaluation unit under consideration for wind erosion factors, the higher score of 1 is assigned to sand class which is considered the very highest susceptible class to the wind erosion. Sand loam class has score of 2 which is highly susceptible, loamy sand class was assigned a score of 3 which is moderately susceptible and loam class was assigned a score of 4 which is slightly susceptible. The Libyan Agriculture Ministry determined the types of soil, which is are concerned in this study. Table (8.5) shows the score of soil texture classes and figure (8.7) the suitability soil texture map.

Table 8.5 soil texture suitability classes

Soil type	Score	Suitability
Sand	1	Very high
Sand Loam	2	High
Loamy Sand	3	Moderate
Loam	4	Slight

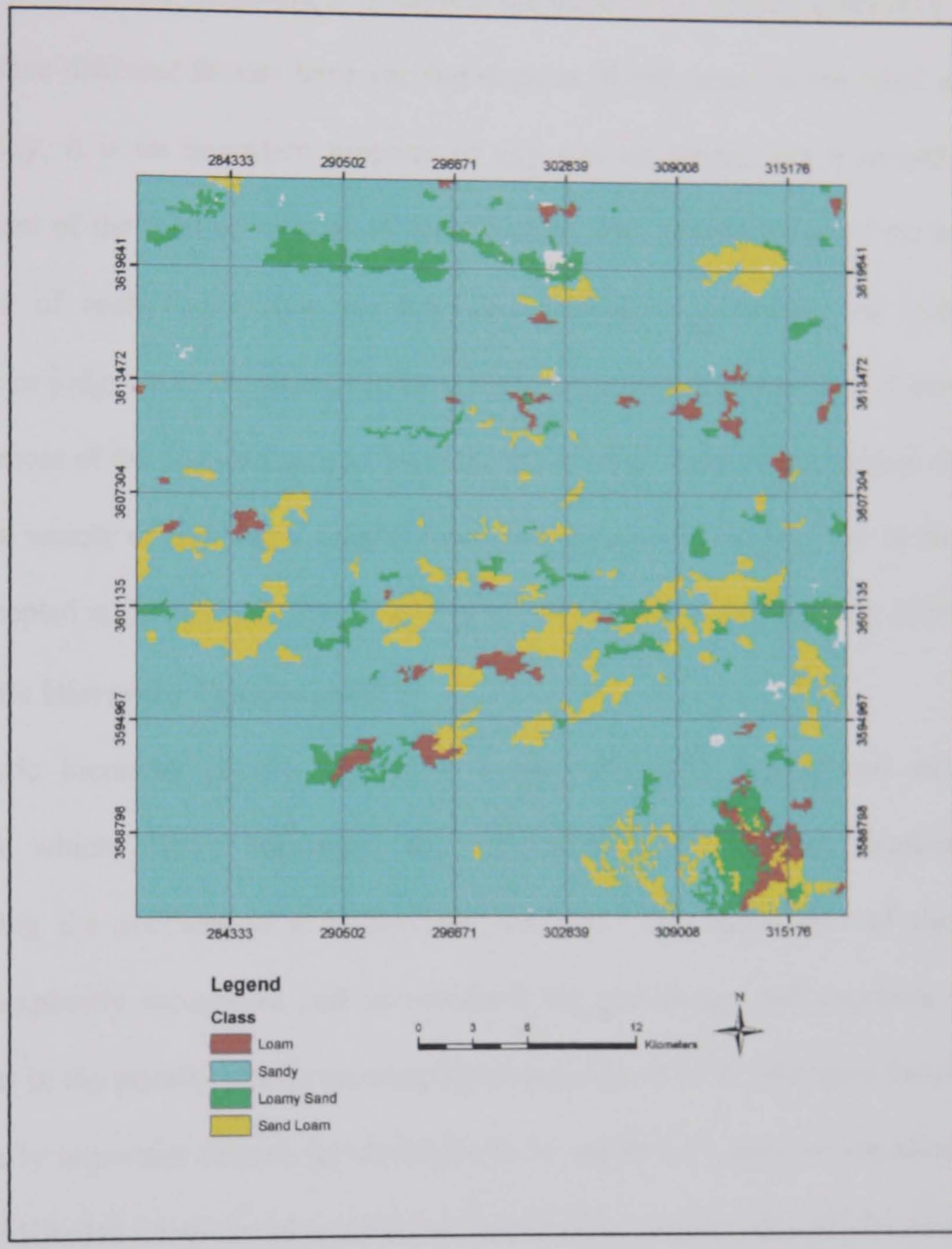


Figure (8.7) suitability soil texture map

8.2.2.3 Calculating the criteria importance-weighting factor

The purpose of criteria weighting is to express the importance of each criterion to other criteria. Since different factors have varying degrees of influence on the wind erosion susceptibility, it is an important property of any site suitability that it should allow measurement of the relative weights of these factors. The determination of the relative importance of each factor is a problem that depends significantly on individual preference or judgement, supplemented by a mathematical tool. In the case of this study the preferences of the decision makers were applied as weights to the evaluation criteria. Although a variety of techniques exist for the development of weights, one of the most widely accepted is the Analytic Hierarchy Process (AHP) proposed by Saaty, (1980)

- **Analytic Hierarchy Process (AHP)**

The analytic hierarchy process (AHP) is a comprehensive, logical and structural framework which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure. The application of the AHP approach explicitly recognizes and incorporates the knowledge and expertise of the participants in the priority setting process, by making use of their subjective judgments, a particularly important feature for decisions to be made on a poor information base. However AHP also integrates objectively measured information (e.g., yields) where this information is available.

The procedures consist of two major steps: generation of the pairwise comparison matrix and criterion weights computation.

- **Pairwise comparison matrix**

In the *PAIRWISE* comparison method the decision-maker is asked to give the relative importance to the criteria by comparing them two by two. In the Pairwise comparison matrix, a points rating scale is developed as illustrated in table 8.6. The nine-point scale expresses the relative importance of relevant factor against the others and range from less important (extremely, very, strongly, and moderately) through equally important to more important (extremely, very, strongly, and moderately).

Table 8.6 Points rating scale

<table>
<tr><td>9</td><td>Extremely</td><td rowspan="4">More important</td></tr>
<tr><td>7</td><td>Very strongly</td></tr>
<tr><td>5</td><td>Strongly</td></tr>
<tr><td>3</td><td>Moderately</td></tr>
<tr><td>1</td><td>Equally</td><td>Equally</td></tr>
<tr><td>1/3</td><td>Moderately</td><td rowspan="4">Less important</td></tr>
<tr><td>1/5</td><td>Strongly</td></tr>
<tr><td>1/7</td><td>Very strongly</td></tr>
<tr><td>1/9</td><td>Extremely</td></tr>
</table>

From the table it can be seen that a rating of 1/9 is considered to be the least important priority whilst 9 is considered to be the most important priority. In other words, the matrix priority ranking determines the degree of importance of each factor against the other ones. The scores are placed in the right corner of the pairwise comparison matrix (table 8.7). Since each factor is equal to itself, the diagonal is filled with 1s, the lower triangular half of the matrix filled using the assumption that, if criterion A receives a score of 2 relative to Criterion B, Criterion B, should receive a score of ½ when compared to criterion.

Table (8.7) Pairwise comparison matrix table

	Agricultural Factor	Slope Factor	Soil type Factor	Rainfall Factor
Agricultural factor	1	5	9	7
Slope factor	1/5	1	7	5
Soil type factor	1/9	1/7	1	7
Rainfall factor	1/7	1/5	1/7	1

Computation of the criteria weights

This step involves the following operations: (a) sum the value in each column of the pairwise comparison matrix; (b) divide each element in the matrix by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix); and (c) compute the average of the elements in each row of the normalized matrix, that is divide the sum of normalized scores for each row by 4 (the number of criteria). These average values provide an estimate of the relative importance of the criteria being compared (table 8.8).

Table (8.8) Computation of the criteria weights

Criterion	Normalized matrix				Average
Agricultural factor	1/1.45 =0.69	5/6.34 = 0.79	9/17.14 =0.53	7/20 =0.35	0.59
Slope factor	0.2/1.45 =0.14	1/6.34 =0.16	7/17.14 =0.14	5/20 =0.25	0.08
Soil type factor	0.1/1.45 =0.07	0.14/6.34 =0.02	1/17.14 =0.06	7/20 =0.35	0.12
Rainfall factor	0.14/1.45 =0.07	0.20/6.34 =0.03	0.14/17.14 =0.01	1/20 =0.05	0.04

Table (8.9) weight of selecting area vulnerability to wind erosion

	Criterion factors	Weights
1	Agricultural factor	0.59
2	Soil type	0.12
3	Slope factor	0.08
4	Rainfall	0.04

8.2.2.4 Performing the final composite suitability analysis

Having obtained the suitability factor and importance weight for each factor, a combination of all factors is achieved by overlaying all relevant suitability factors as grids to produce composite suitability as shown in figure 8.8

To calculate the final score for area vulnerability to wind erosion, the following formula has been implemented:

Suitability = (agricultural suitability * 0.59) + (soil type suitability * 0.12) +(slope suitability *0.08) + (rainfall *0.04).

In the result, all the suitable areas for land susceptibility to wind erosion have 1 and the others have value 0 as not suitable. Figure 8.11, shows the final composite suitability map. To produce categories or ranking of susceptible site for wind erosion score, this is done simply by multiplying the weighting factor by 4 and writing the formula as follows:

Suitability = (agricultural suitability * 2.4) + (slope suitability * 0.48) +(slope suitability *0.32) + (climate *0.16)

The result shows that a suitability score of 4 has been assigned to polygons of very high susceptible site, 3 to high site, 2 to moderate susceptible site, and less than 1 to slight vulnerable site. Figure 8,11 shows the final composite vulnerability map

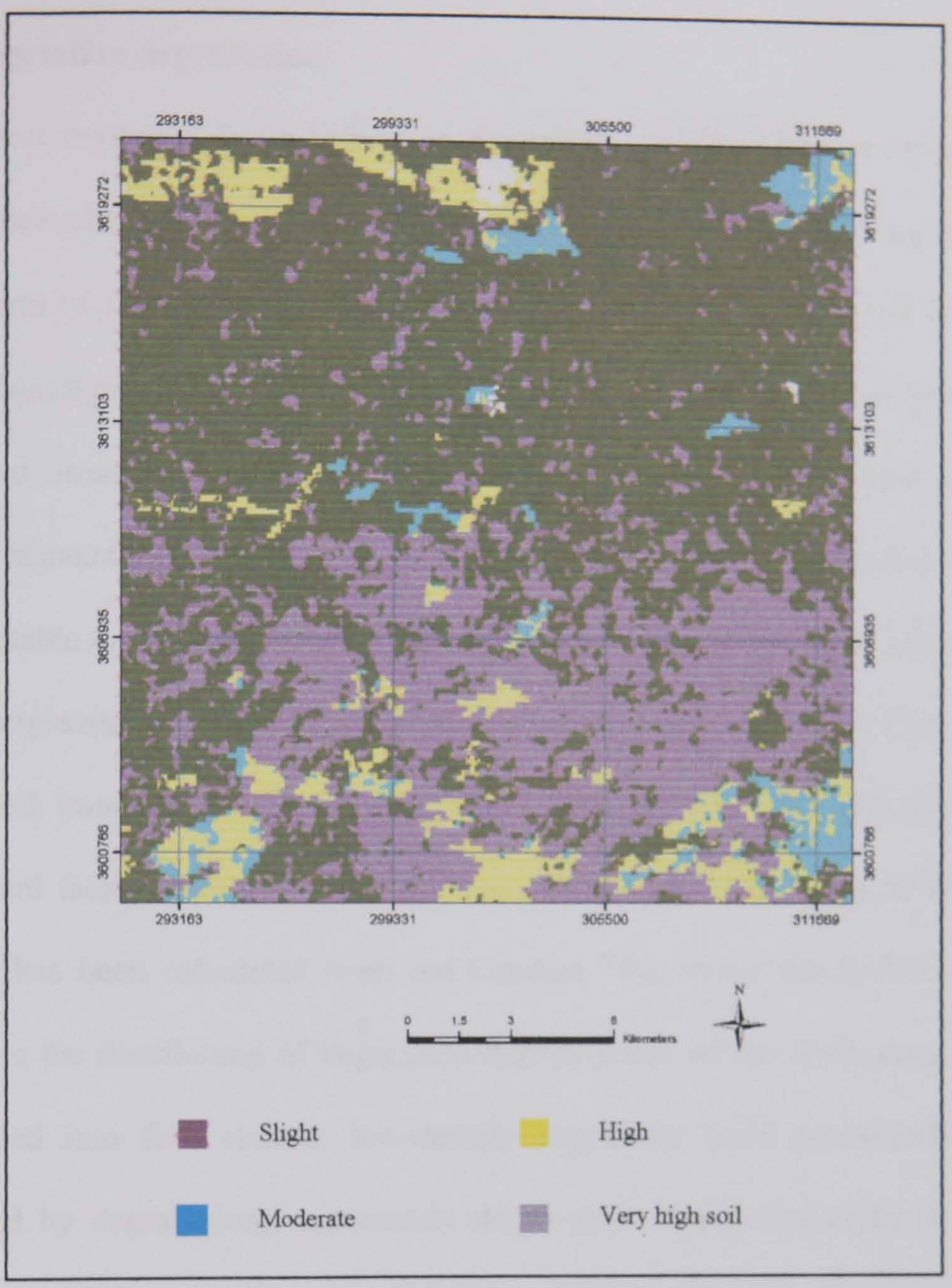


Figure 8.8 the final composite vulnerability map

- **Vegetation degradation**

The most important factor indicating degradation of vegetation cover is the decline of land productivity. This is due to many factors such as removal of top fertile soils and reduction of organic matter. The land cover classes were reordered in terms of their reduction in productivity, specifically the areas of strong decrease of productivity are in irrigated areas followed by rangeland then rainfed agriculture area etc. The second factor relevant to vegetation degradation is the appearance of unpalatable plants in place of palatable ones. After quarried areas, the most affected are the marginal lands, where the overgrazing and the ploughing of this type of land cover are very intensive. This is followed, in order, by irrigated area, desert rangeland, orchards, and rainfed agriculture. The third factor indicating the vegetation degradation is the index of vegetation cover, which has been calculated from the Landsat TM, where the SAVI can assist us to estimate the distribution of vegetation density cover of the study areas. The areas are classified into four classes: low-density vegetation areas (considered to be highly affected by degradation); moderately dense vegetation cover areas (considered to be moderately affected by degradation), high-density vegetation cover (considered to be slightly affected by degradation) and very high-density vegetation cover (considered not to be affected by degradation). These classes are shown in figure (8.9).

- **Salinisation factor**

Soil salinity in the study area is the direct result of the irrigation activity. This means that the most important factors relevant to this are ground water quality, productivity of fields, soil type and climatic condition (mainly rainfall). Examining these factors, it was found that soil characteristics (desert soil) and also the agricultural productivity in this case study strongly correlate with water quality. Thus it is concluded that water quality is the predominant factor to classify the salinity of irrigated areas. The water quality has declined rapidly over time. This conclusion permitted us to classify the salinity of irrigated areas into three classes: areas irrigated from the earliest times up to 1992 (considered highly affected by salinity); those areas irrigated from 1992 up to 1996 (moderately affected); and those areas irrigated from 1996 up to 2000 (slightly affected) These areas are shown in figure 8.10

8.2.3 General desertification map

The production of a general desertification map, which synthesizes all types of land degradation, is achieved through the following three steps:

a) First Step: combination of wind erosion with vegetation degradation

The wind erosion factor directly affects the vegetation cover, and it is considered a main cause of vegetation degradation. In this step, integration of the result of wind erosion with the vegetation degradation map, which was obtained previously, creates an intermediate desertification map with four classes.

b) Second Step: integration of salinisation

This step was achieved simply by overlaying the salinisation map with its different degrees with the results of first step. The result shows a general land degradation (desertification) map of the study area. Figure 8.11 shows all types of land degradation including the general desertification map and areas in (ha) shown in table 6.8.

Table (8.10) Desertification Assessment by type of degradation

Desertification Assessment by type of degradation					
Degree of assessment		**Slight**	**Moderate**	**High**	**Very High**
Wind erosion	Area (ha)	46177	8500	2054	57706
	%	40.6	7.4	1.8	50.4
Vegetation degradation	Area (ha)	21195	23656	31336	38250
	%	18.8	20.7	27.4	33.4
Salinization	Area (ha)	6690	9219	9050	0
	%	6	8	7.9	0

8.3 Conclusion

The current chapter discussed the desertification processes and their effect by using GIS to develop a criterion to be used for Desertification Mapping Units (DMU) using the most important features of desertification in the study area. The layer of desertification mapping units permits the analysis and assessment of different types of land degradation. It is necessary to identify the various indicators, which will provide the relevant information to define the desertification prone areas. In this chapter, the integrated approach is of utmost importance for the desertification study, which reflects the complexity of the desertification process. So the desertification assessment in this study is the output of a combination of wind erosion factors, vegetation degradation factors and salinisation factors. Finally the results of this study (table 8.10) demonstrate the severity of desertification problems at all levels, mainly by the vegetation degradation process (61.0% of the study area is severly to very severely vulnerable), and, wind erosion process (51.0% of the study area is severly to very severly vulnerable). Without doubt, these results argue the severity of desertification in the study area.

The overall accuracy of any GIS model is important, because it reflects on the integrity of the final conclusions. The accuracy of this chapter was determined in relation to data availability. Unfortunately, many pieces of data were not available, which restricted the process to applying only three of the 8 factors related to desertification processes.

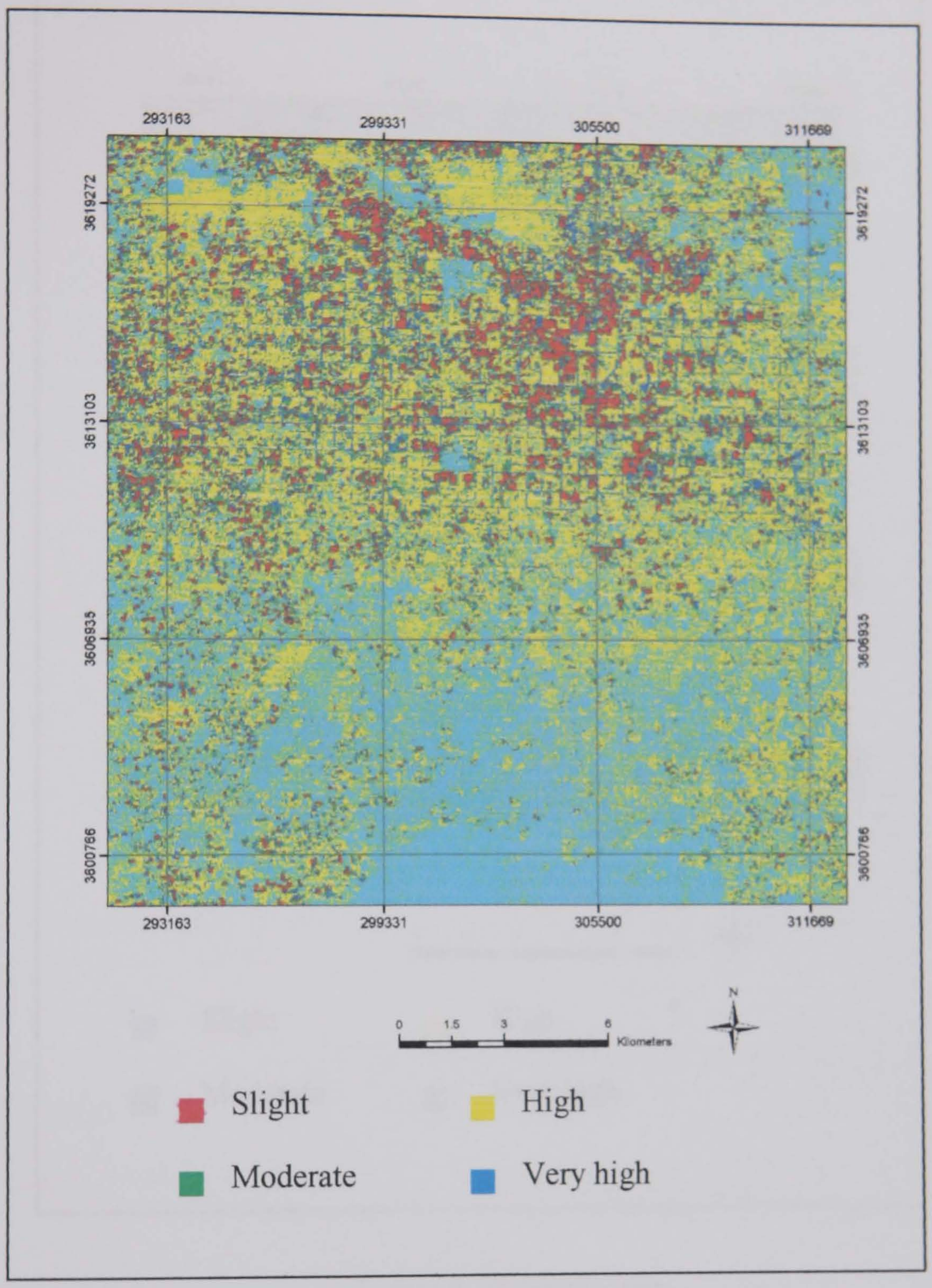


Figure (8.9) vegetation degradation map

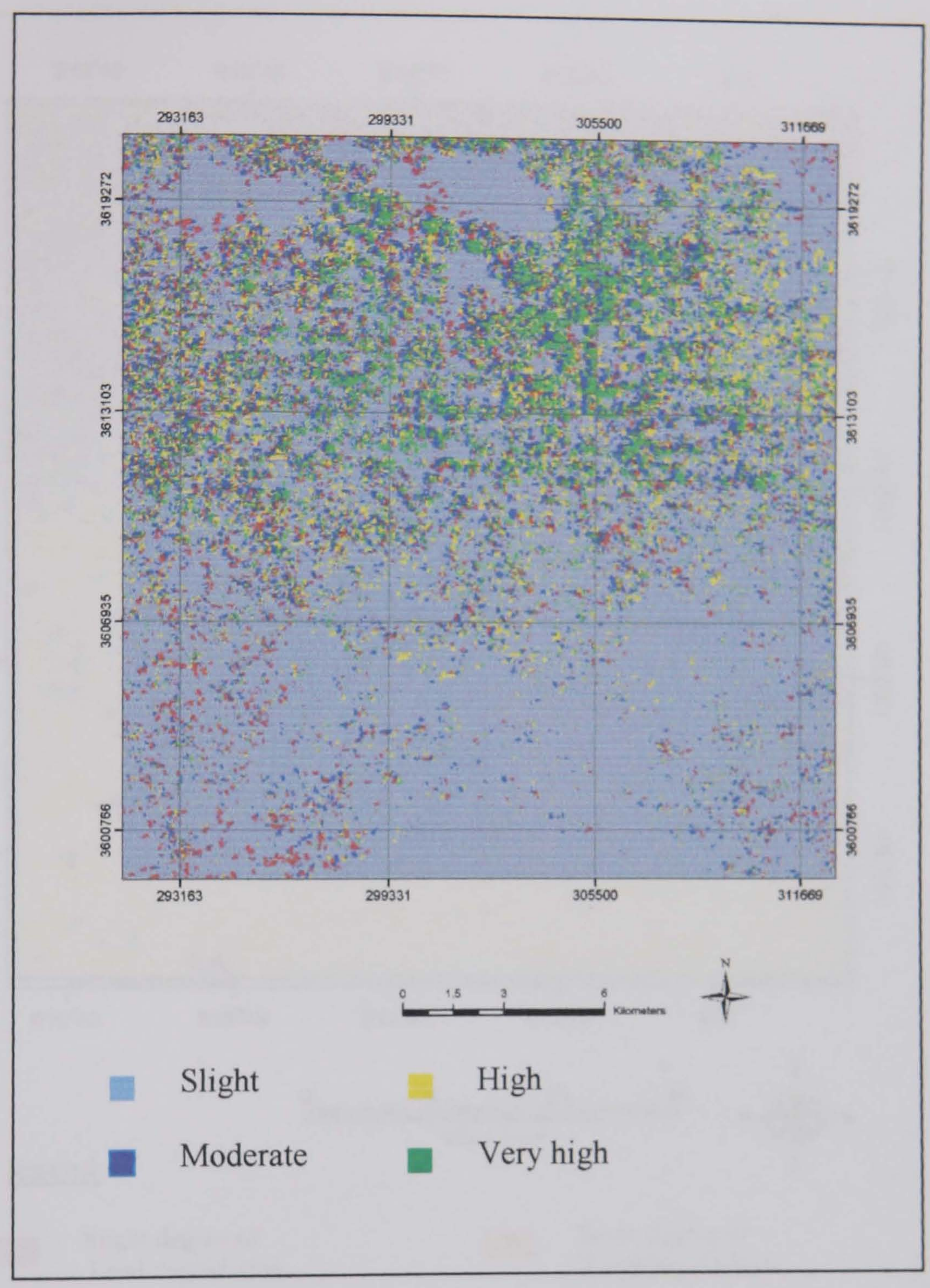


Figure 8.10 salinity map

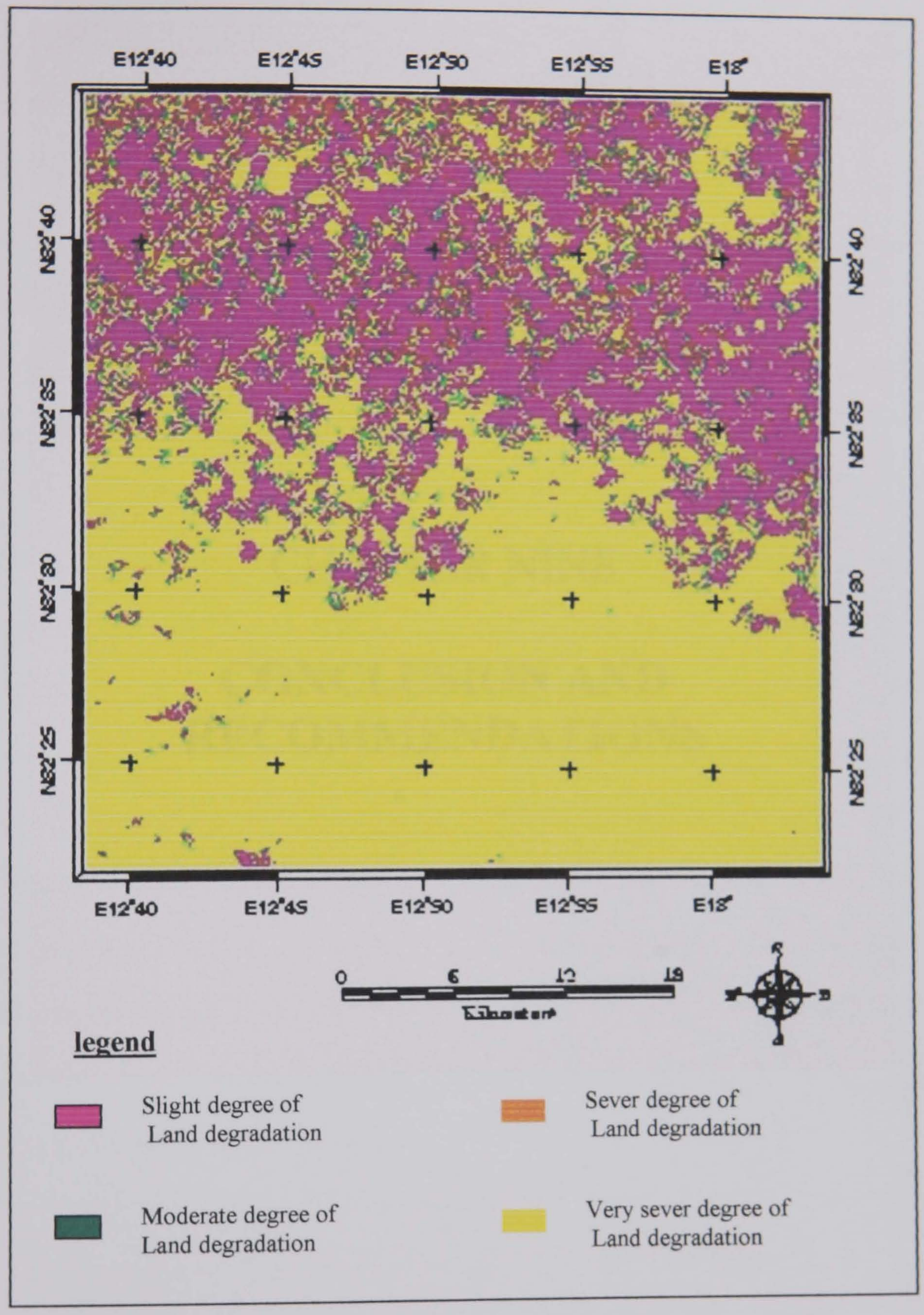


Figure 8.11 desertification map

CHAPTER NINE

CONCLUSION AND RECOMMENDATIONS

9. Conclusion

In this study, desertification is defined as "land degradation in arid-semi arid and dry sub humid areas resulting from various factors, including climate variation and human activities". Guided by this definition, three types of land degradation, vegetation degradation, wind erosion, and salinisation areas affected by these types were classified and represented on the final desertification map. This study has revealed a number of results of which the following are considered the most important

The study took four directions; the first was to produce land cover maps using Landsat TM data using image-processing techniques for the analysis and identification and extraction of land cover information. The second was to detect and evaluate the dynamics of the changes of the land cover of the area of study during the period from 1988 to 2000. The third was to map vegetation cover using Soil Adjust Vegetation Index (SAVI) and calculate the changes from year 1988 to 2000. The results of SAVI images are alone not suitable to distinguish different vegetation types, but it is possible to monitor the actual degree of vegetation cover. This can be a great advantage because vegetation classification and description of different authors of the same region can be extremely variable.

The results which were extracted from remotely sensed data have been used to establish a model for developing the indicators for Desertification Mapping Units with regional consideration by integrating and analysing the data, which had been extracted using remote sensing, along with other related data sets, in GIS.

The fourth system process comprises two models starting with the areas susceptible to wind erosion and a suitability model, for the analysis and assessment of land cover, to determine the potential land for wind erosion. The model is capable of introducing many factors into the analysis as well as incorporating expert knowledge related to factor weights and land suitability assessment. The Analytic Hierarchy Process, AHP, has been used to carry out the mathematical computations related to the weighting procedures. The second process was to produce the general desertification map which synthesized all types of land degradation. This was achieved through the combination of the wind erosion map with the vegetation degradation map then integration of these results with the salinization map. The final result shows a general land degradation (desertification) map of the study area.

Remote sensing and geographic information system (GIS) techniques allow the integration of many factors and data with different forms, with potential applications in the design of new methodologies for dealing with desertification problems. The accuracy of data entered into the GIS in this study depends largely on the original form of data, whether it is digital satellite data or hardcopy thematic maps. Other considerations are the scale and resolution of data. Unfortunately there is no reference data (previous desertification maps) on this study area to calculate the accuracy assessment for the final result of this study.

9.1 Limitations

Desertification analysis and mapping using remote sensing and GIS constitute the originality of this research. There is a lack of remote sensing and GIS in desertification, and few studies have been found which map desertification using such tools. This study concluded that there is a need to develop a standard method and criteria for desertification studies. This method must apply remote sensing data in such a way as to map and assess, both continuously and periodically, land degradation processes. In this study the absence of data availability restricted the method to using just three indicators for desertification. The using SAVI index alone not able of distinguishing different vegetation types. Another limitation of the study area is the very limited amount of published reference material available on Libyan cases of desertification.

9.2 Recommendations

This work has demonstrated the necessity to generalize the benefit of remote sensing and GIS in monitoring land degradation and the choice of experimental locations to apply the best methods for desertification and to observe the results periodically. Also it would be useful to create a land resources database to help in monitoring desertification. In particular, the following recommendations are suggested:

- The present number of meteorological stations in Libya is inadequate and should be improved and intensified especially in the southern parts of the country.

- Increasing the accuracy of base maps of land cover by using high-resolution satellite imagery such as IKONOS will provide the ability to discriminate between different land features.

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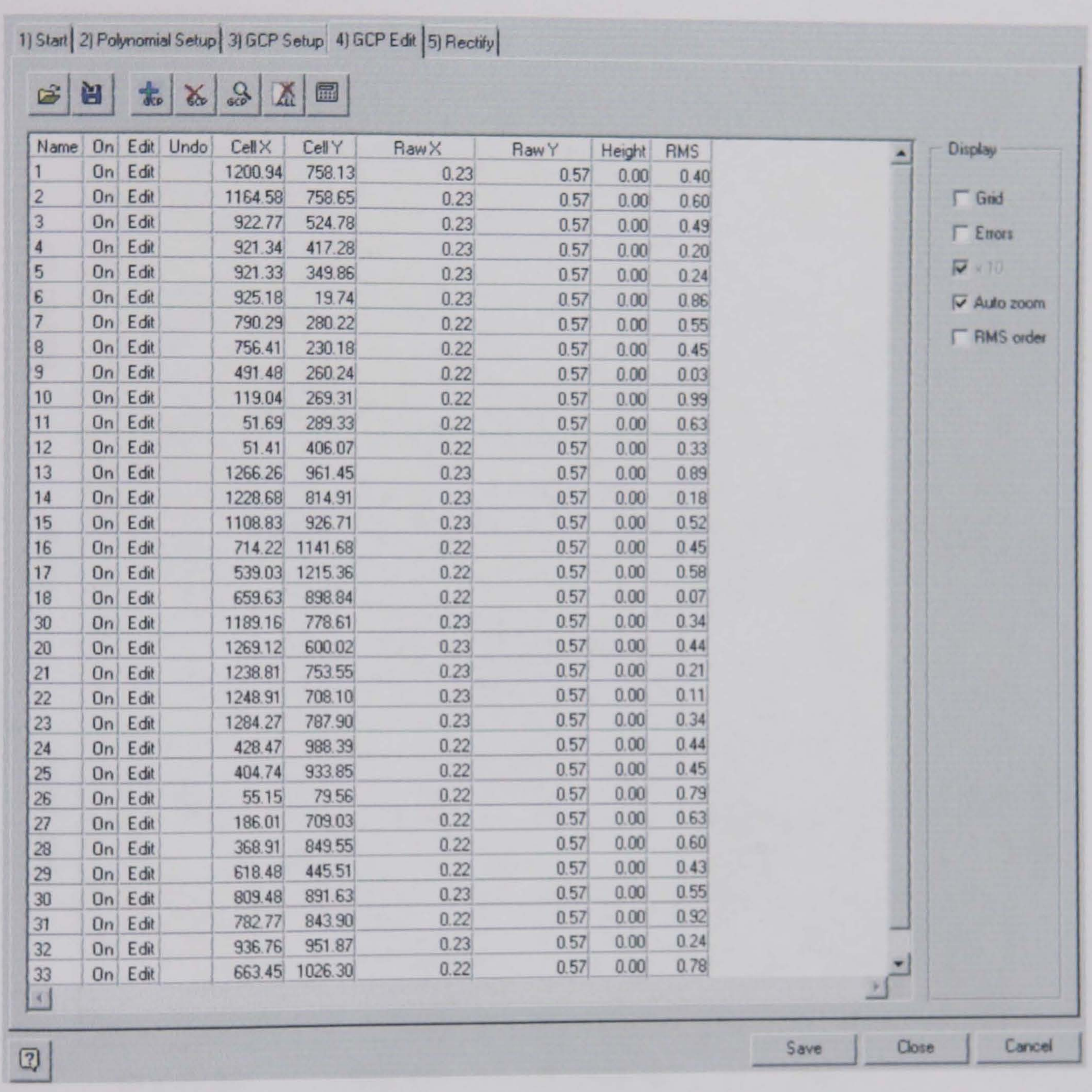
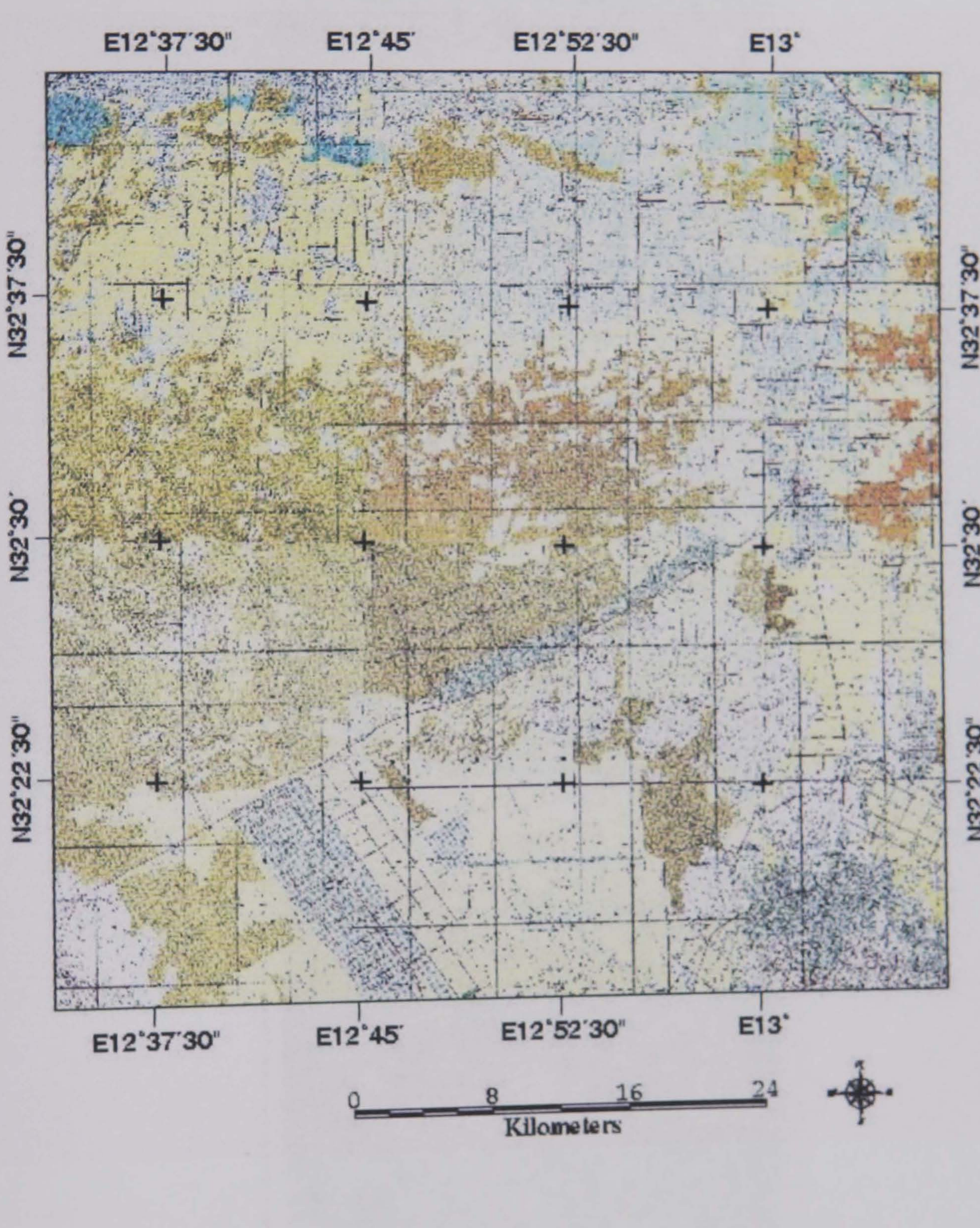
Appendix A: Geometric correction points (GCP)

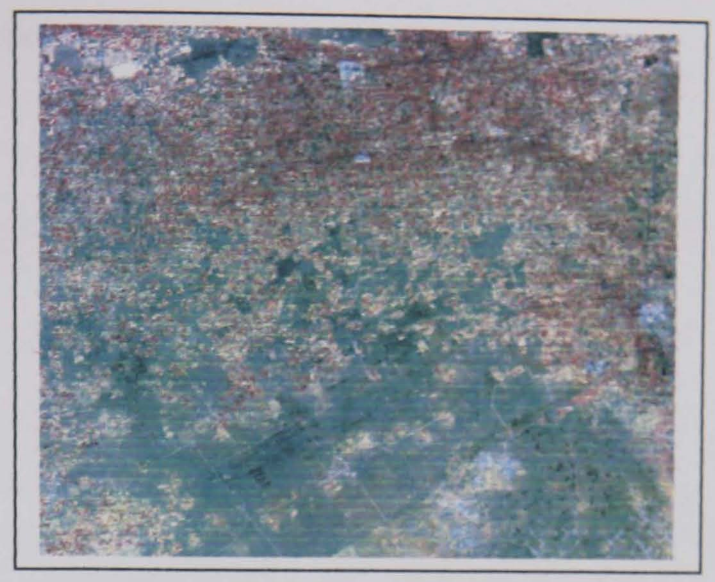


Name	On	Edit	Undo	Cell X	Cell Y	Raw X	Raw Y	Height	RMS
1	On	Edit		1200.94	758.13	0.23	0.57	0.00	0.40
2	On	Edit		1164.58	758.65	0.23	0.57	0.00	0.60
3	On	Edit		922.77	524.78	0.23	0.57	0.00	0.49
4	On	Edit		921.34	417.28	0.23	0.57	0.00	0.20
5	On	Edit		921.33	349.86	0.23	0.57	0.00	0.24
6	On	Edit		925.18	19.74	0.23	0.57	0.00	0.86
7	On	Edit		790.29	280.22	0.22	0.57	0.00	0.55
8	On	Edit		756.41	230.18	0.22	0.57	0.00	0.45
9	On	Edit		491.48	260.24	0.22	0.57	0.00	0.03
10	On	Edit		119.04	269.31	0.22	0.57	0.00	0.99
11	On	Edit		51.69	289.33	0.22	0.57	0.00	0.63
12	On	Edit		51.41	406.07	0.22	0.57	0.00	0.33
13	On	Edit		1266.26	961.45	0.23	0.57	0.00	0.89
14	On	Edit		1228.68	814.91	0.23	0.57	0.00	0.18
15	On	Edit		1108.83	926.71	0.23	0.57	0.00	0.52
16	On	Edit		714.22	1141.68	0.22	0.57	0.00	0.45
17	On	Edit		539.03	1215.36	0.22	0.57	0.00	0.58
18	On	Edit		659.63	898.84	0.22	0.57	0.00	0.07
30	On	Edit		1189.16	778.61	0.23	0.57	0.00	0.34
20	On	Edit		1269.12	600.02	0.23	0.57	0.00	0.44
21	On	Edit		1238.81	753.55	0.23	0.57	0.00	0.21
22	On	Edit		1248.91	708.10	0.23	0.57	0.00	0.11
23	On	Edit		1284.27	787.90	0.23	0.57	0.00	0.34
24	On	Edit		428.47	988.39	0.22	0.57	0.00	0.44
25	On	Edit		404.74	933.85	0.22	0.57	0.00	0.45
26	On	Edit		55.15	79.56	0.22	0.57	0.00	0.79
27	On	Edit		186.01	709.03	0.22	0.57	0.00	0.63
28	On	Edit		368.91	849.55	0.22	0.57	0.00	0.60
29	On	Edit		618.48	445.51	0.22	0.57	0.00	0.43
30	On	Edit		809.48	891.63	0.23	0.57	0.00	0.55
31	On	Edit		782.77	843.90	0.22	0.57	0.00	0.92
32	On	Edit		936.76	951.87	0.23	0.57	0.00	0.24
33	On	Edit		663.45	1026.30	0.22	0.57	0.00	0.78

Appendix B: Topographical Mosaic Map



Appendix C1: Reference satellite data



SPOT 4 Resolution(20m)

SPOT 5 Resolution(2.5m)

IRS- PAN Resolution(5m)

Appendix C2: Reference satellite data

Field data recording sheet. Site ID:--------------- Date: ----------------

<table>
<tr><td colspan="6">Location</td></tr>
<tr><td colspan="6">Site Name:</td></tr>
<tr><td rowspan="2">GPS data</td><td>Latitude</td><td>Longitude</td><td colspan="3">Elevation</td></tr>
<tr><td></td><td></td><td colspan="3"></td></tr>
<tr><td colspan="6">Land cover description</td></tr>
<tr><td colspan="3">Vegetation cover</td><td colspan="3">%</td></tr>
<tr><td colspan="3"></td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Cultivated land</td><td>Permanent Crops (Pc)</td><td colspan="4"></td></tr>
<tr><td>Temporary Crops (Tc)</td><td colspan="4"></td></tr>
<tr><td rowspan="3">Settlement</td><td>Residential (Rs):</td><td colspan="4"></td></tr>
<tr><td>Commercial (Co):</td><td colspan="4"></td></tr>
<tr><td>Transport (Tr):</td><td colspan="4"></td></tr>
<tr><td colspan="6">Soil description</td></tr>
<tr><td colspan="2" rowspan="2">Photo number

Four cardinal directions (North, South, East & West)</td><td>N</td><td>S</td><td>E</td><td>W</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Relevant information (if any)</td></tr>
</table>

Appendix D: Typical land degradation features

Appendix E: The optimum index factor (OIF)

Bands Ranking	Total (Std)	Total (corr.coeff)	OIF
541	175.064	2.071	84.5
741	156.414	2.1	74.5
341	165.643	2.293	72.2
754	163.43	2.27	72
542	161.371	2.249	71.8
543	163.659	2.283	71.7
743	163.009	2.335	69.8
742	160.721	2.304	69.8
421	154.355	2.341	65.9
432	160.95	2.499	64.4
751	153.128	2.469	62
531	153.357	2.491	61.6
731	152.707	2.52	60.6
521	151.069	2.495	60.5
752	157.435	2.637	59.7
721	150.419	2.527	59.5